Research Report

Final Report *January 1969*

U.S. AGRICULTURE: POTENTIAL VULNERABILITIES

Prepared for:

OFFICE OF CIVIL DEFENSE
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WASHINGTON, D.C. 20310

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OCD WORK UNIT 3535A

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U.S. AGRICULTURE: POTENTIAL VULNERABILITIES

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DETACHABLE SUMMARY

Selected aspects of the vulnerability of U.S. agriculture to nuclear attack were investigated. The study areas can be roughly divided into studies of sensitivity, agricultural practices, and geographical imbalances.

Sensitivity studies were conducted relative to the date of attack (as an indicator of crop cycles), foliar contamination parameters, and vulnerability criteria. On the average, the most vulnerable month of attack is June. If U.S. agriculture as a whole is considered, the vulnerability does not vary too greatly with date of attack, because individual variations tend to average out. Results for individual crops or regions are much more sensitive. The sensitivity to foliar contamination parameters was investigated using an improved beta dose model. A variety of foliar contamination models were tested with ranges of the retention factor f_{ℓ}, and the soil roughness attenuation factor, Q_{β}. None of the uncertainties in the parameters or models lead to differences in the total dose by factors of more than about two, except under relatively improbable circumstances. An increase in the total dose by a factor of two would have essentially the same effect as reducing the dose criteria for damage by half. Such a reduction leads to a variation of crop survival of less

than 10 percent. Since so many other factors can influence the results by this amount or more, a large effort for the purpose of improving models and determining parameters more precisely does not seem justified. However, the status of fallout vulnerability of crops and livestock should be reviewed periodically, perhaps every five years, to determine whether changes in the knowledge of fallout effects or in potential attack patterns might be significant enough to warrant development of new models and data.

The agricultural practices surveyed were the application of fertilizers and pesticides, irrigation and cultivation, farm use of petroleum and electricity, and trends in cattle and poultry production. Availability of petroleum and fertilizers would appear to be the most serious questions for the vulnerability of agriculture. The main food and feed crops are produced almost exclusively with the aid of petroleum powered mechanical equipment. These crops are also quite responsive to changes in soil nutrients and are currently receiving near optimal fertilization. Loss of fertilizers could conceivably cut production in half. Pesticides are probably less important than the above but more important than irrigation, cultivation, and electricity for the production of the main food and feed crops. Fruits, vegetables, potatoes, sugar beets, and rice are much more dependent on the last mentioned agricultural practices, and dairy, poultry, and other livestock products depend on electricity; thus, the nutritional balance and palatability of the postattack diet might be affected. Cattle production trends are toward continued dispersion, with concomitant low vulnerability. However, transportation appears to be increasingly essential to production and may constitute a vulnerability. Poultry trends are toward increasing concentration, but in areas of relatively low target value. Livestock practices, therefore, are not at the present particularly sensitive as potential postattack problems. Most of these conclusions support those of an eight-year-old study of similar questions, with the possible exception that electricity was judged a greater potential vulnerability at that time. Another review is suggested after about the same time lapse. In the meantime, the dependence of farm production on petroleum and fertilizers should be reinvestigated in more detail, and damage assessment models should be developed.

Geographical imbalances between food production, processing, and consumption were investigated on a regional basis. Results were obtained both for conditions before attack and for conditions after standard attacks (1975 time frame). The preattack imbalances are so striking that further imbalances caused by an attack are not likely to be very noticeable. For the postulated attacks, in fact, the imbalance appeared to lessen with respect to the requirements made on food transportation. However, the results were based on gross measures of the resources--food value in calories for production, manufacturing value added for processing, and population for consumption. Investigation of commodity imbalances might paint a more disturbing picture. Management of distribution was also suggested as a potential vulnerability.

Management, as usual in postattack studies, again seems to be the key to the whole agricultural situation during the postattack period. Even though the combined effects of fallout radiation, petroleum shortages, and fertilizer deficiencies could strain the agricultural system, production is still likely to exceed minimum survivor demands. Because of extensive disruption of processing and distribution channels, as well as of the normal patterns of demand and supply, preattack market systems may not be sufficient to get food from producers to consumers in time. It would be desirable to have a postattack information and management system with the function of determining where resources are available and where they are needed. The Department of Agriculture, with its network of county agents, is the logical administrator for such a system. The framework for gathering and disseminating information is already established, and a civil defense function is also operating. It is suggested that these two functions be more closely tied to a management information system that is structured to enable allocation decisions to be made quickly and effectively on the basis of available information.

ABSTRACT

This report presents the results of essentially independent studies on selected aspects of U.S. agriculture for the identification of potential vulnerabilities under nuclear attack. Sensitivity studies to date of attack, foliar contamination parameters, and vulnerability criteria show that uncertainties in these areas are relatively unimportant for total survival estimates. The characteristics of fertilizer and pesticide application, cultivation and irrigation, farm use of petroleum and electricity, and beef cattle and poultry production imply that the most serious sources of vulnerability relate to fertilizer and petroleum. Geographical imbalances between production, processing, and distribution of food were not enhanced after the attacks postulated.

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I INTRODUCTION

Background

The possible existence of unsuspected vulnerabilities to nuclear attack in the United States has been the worry of civil and military defense planners for many years. Most damage assessment analyses seem to indicate optimistically that survival of individual resources (population, industry, agriculture, etc.) would be adequate after credible nuclear attacks. However, widespread concern has been voiced over the validity of certain assumptions, particularly those that concern the interactions of several systems, and over the possible exclusion from consideration of important classes of problems. One attempt at investigating these possibilities has been the NESS (National Entity Survival Study) conducted for the Office of Civil Defense by Stanford Research Institute.

Since food and water are the primary requisites for survival, agriculture is easily identified as one of the essential elements of the national entity. The ability of farms to produce livestock, food crops, and feed crops is therefore one of the subjects of NESS. In a previous report,[1] a national damage assessment for agriculture was presented and the models used in the vulnerability analyses were described. The following is quoted for the convenience of the reader:

> Two hypothetical attacks, designated as SRI A and SRI B, were used in the assessment of national entity vulnerability. Both attacks were supplied by OCD; the former was a counterforce attack, while the latter was similar but added a countervalue objective. The total yield delivered in SRI A was

approximately 1,300 MT, and this was almost doubled in SRI B. For purposes of determining the resource data base, it was assumed that the attacks occurred in 1975. Winds for fallout prediction were taken from meteorological records for a day in June. June 15 was selected as the exact date of attack; this choice was influenced by the expectation that on such a date the planted crops might be relatively more vulnerable to fallout radiation than at other times of the year.

Further material from that report will be relied on heavily in the present discussion. In brief, the survival levels of livestock, food crops, and feed crops were all in reasonably good balance with population survival, and no specific danger points were identified. The models included radiation effects on plants and animals and the additional denial of crop land to farmers from excessive fallout radiation.

Both during the course of that research and afterward, however, questions about the validity of the results arose. Many of the assumptions made were for lack of more complete information. Among these were the functioning of a farm product transportation and distribution system, the availability of farm chemicals and petroleum, and the representativeness of the agriculture data base. Other questions that could not be considered in the previous study included the effect of field denial at cultivation times, the time of year at which the most serious agricultural effects would be felt, and the extent to which changes in the parameters of the vulnerability models might affect the results.

Objective

Accordingly, the current research effort has as its objective the identification of aspects of the agricultural system or of the models describing it that could lead to vulnerability estimates substantially more serious than are now being made.

Scope

The above objective is sufficiently broad that no facet of agriculture should be exempt from study. Practical considerations, however, limited the research to a few fairly specific questions. Even among these few, several were not amenable to investigation at the desired level of effort. The remaining questions fall into three classes--sensitivity studies, agricultural practices, and geographic imbalances.

The sensitivity studies apply particularly to the existent models for agricultural damage assessment. The questions addressed were:

1. How much do the results depend on the assumed date of attack?
2. Since the foliar retention model and parameters are inexact, how would the results vary with possible changes?
3. How would the results change if new values for the vulnerability criteria were proposed?

The agricultural practices studied for potential vulnerabilities were:

1. Fertilizers
2. Pesticides
3. Irrigation and Cultivation
4. Petroleum Use
5. Electricity Use
6. Beef Cattle Production
7. Poultry Raising

These practices were studied in only enough detail to indicate whether potential problems might seriously affect the survival of the major agricultural products. No attempt was made to link the potential agricultural problems with any specific predictions of the survival of, say, the chemical industry.

The investigation of geographical imbalances was limited to a survey of preattack patterns of commodity movements and the implications that the postattack survival pattern for agricultural might have for requirements on the transportation system.

II SENSITIVITY STUDIES

When assumptions are questionable, the most direct way to solve the problem is to investigate the assumptions and modify them to fit all known facts. This procedure is likely to be time consuming and difficult, however, and in many cases a sensitivity analysis is sufficient to show whether the important results are affected very much by changes in the assumptions. In the same way, when results vary with variations in the values of input parameters, they can provide useful sensitivity information, as when a particular parameter can in fact take on several different values. The analyses presented in this section deal with the sensitivity of crop survival results to various assumptions and parameters when the basic model described in Reference 1 is used.

Sensitivity to Date of Attack

The survival of a year's production of food and feed crops depends on the date of attack because the plants themselves are only sensitive from the time of emergence until shortly before harvest and because gamma radiation denies fields to farmers for only a few weeks before planting or harvesting. In selecting a date for a hypothetical attack, therefore, a worst case was attempted. Since most crops have been planted by June and few have been harvested, June 15 seemed a likely candidate and was used in 1967. However, the possibility remained that a worse case existed, and the variation from date to date was also of interest.

The date of attack entered the computer damage assessment model as a direct parameter, the day of the year. Planting, harvesting, and plant growth were all related to this day. Results could be obtained for February 15, April 15, May 15, July 15, August 15, September 15, October 15, and December 15, as well as for June 15. In order to save computing time, the results for all crops were obtained only for Region 6. Region 6, however, is the largest agriculturally producing region in the United States, and produces significant quantities of almost every crop studied. It is a particularly large producer of wheat.

A typical result pattern, for spring wheat, is shown in Figure 1. The acres accessible to farmers vary only slightly over the year, dropping a few months before planting and then rising after harvest. The percentage accessible never reaches 100 percent because a small percentage of farm workers (as represented by the rural population) dies from radiation and a corresponding percentage of the acreage is considered to be unusable for a year after attack. The percentage of the acreage surviving radiation effects on the crops themselves, however, is 100 percent for most of the year, dropping off rapidly during the growing season. Net survival tends to follow radiation survival during the growing season and acreage accessibility during the rest of the year.

Results for other crops are shown in Table 1. Minimum survival is underlined, showing quite a spread in most sensitive attack dates. The ratio of maximum crop loss to minimum crop loss tends to be about 2/1. Potato production is hardest hit, surviving less than 40 percent if the attack comes in July. Potatoes also do poorly in July in Region 1 (less than 40 percent survive) but are not seriously affected in Region 8 (over 90 percent survive).

The variation in the month for which the individual crops are most vulnerable suggests that aggregation will reduce the magnitude of the effect. This conclusion is supported by Figure 2, in which total calories for Region 6 are calculated, using the weighting factors from Reference 1. Curves are also shown for human calories and animal calories separately. Human calories survive least well for an attack in May, at about 72 percent of normal, compared with 90 percent in October. For

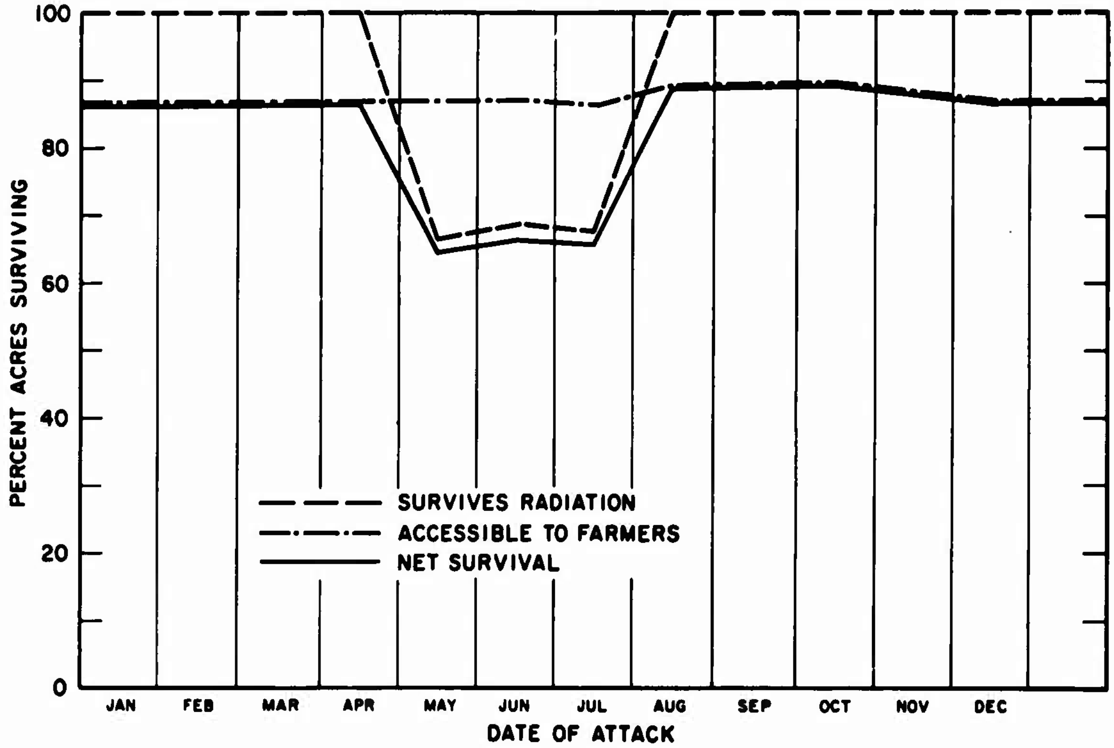

FIG. 1 SPRING WHEAT SURVIVAL, REGION 6

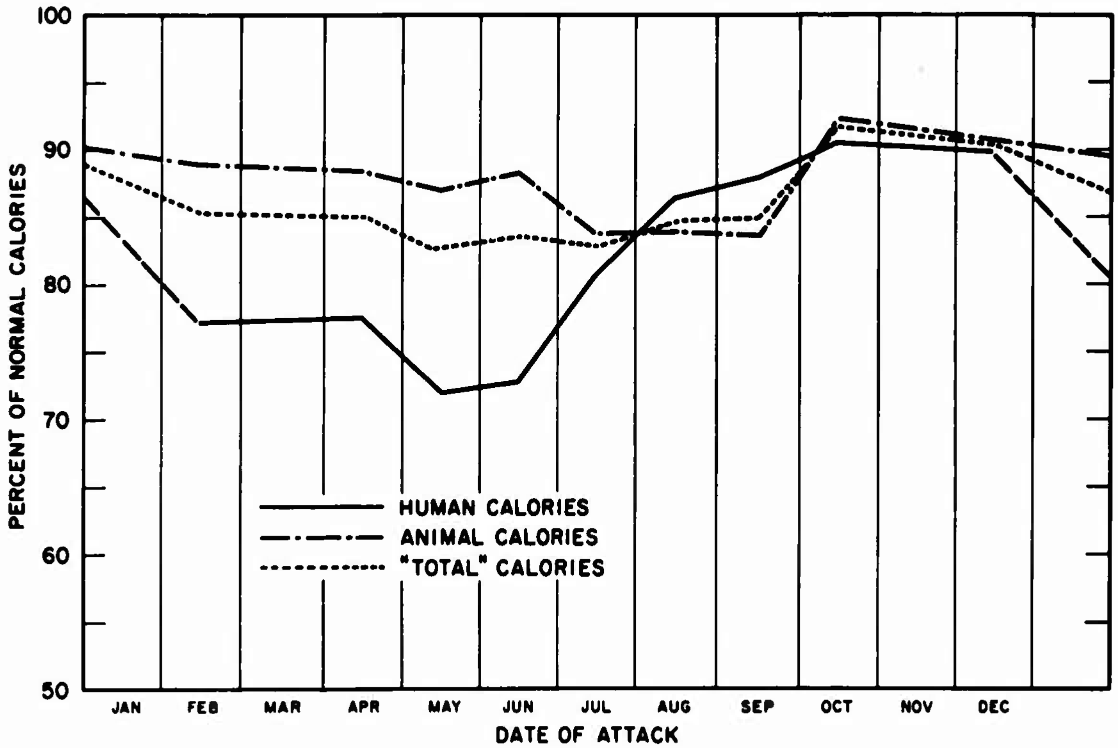

FIG. 2 TOTAL FOOD VALUE, REGION 6

Table 1

NET CROP SURVIVAL BY DATE OF ATTACK
(Percent)

Crop	Crop Code	Feb 15	Apr 15	May 15	June 15	July 15	Aug 15	Sept 15	Oct 15	Dec 15
Corn	21	90.1	90.0	91.0	90.7	83.3	81.9	81.2*	92.3	90.3
Sorghum	22	90.7	90.5	90.2	92.5	81.7	80.6	79.8	92.5	92.3
Wheat, winter	23	66.4	67.4	66.4	67.5	89.2	89.2	89.4	90.6	91.0
Wheat, spring	24	86.8	86.4	64.8	66.6	66.0	89.6	89.6	89.6	86.9
Oats, spring	26	91.4	88.6	76.0	80.1	90.4	93.4	93.4	93.1	91.5
Barley, winter	27	61.5	62.9	62.3	80.4	86.9	86.6	87.7	88.4	88.4
Barley, spring	28	82.6	78.2	60.0	61.0	66.8	86.3	86.3	86.0	82.8
Rice	29	94.7	94.7	100.0	100.0	100.0	100.0	89.5	100.0	94.7
Soybeans	32	92.6	92.6	92.5	94.2	82.2	82.0	82.9	94.2	94.2
Alfalfa	42	77.6	77.0	78.8	88.3	91.6	92.9	93.4	93.4	93.4
Potatoes	50	66.8	64.8	62.6	71.2	39.7	40.5	72.1	72.1	66.9
Sugarbeets	56	84.6	84.7	83.1	77.5	76.4	79.2	86.7	86.4	84.7
Sweetcorn	62	85.8	85.8	88.4	73.2	72.6	88.4	88.4	88.4	85.8

* Underlined figures are minimum survival over the year.

animal feeds, the worst attack date is September, with 83.5 percent surviving, but 92.5 percent survive in October. The total calorie curve is even flatter, varying from 82 percent in May to 92 percent in October. Because the planting and harvest dates vary considerably over the country for any crop, aggregation over the nation would also tend to smooth out the sensitivity to date of attack, and aggregating both over geographic regions and over all crops would result in the smoothest curve of all. One would still expect a twofold difference in net crop loss between summer and late fall, however.

These findings imply that June is probably as representative as any month of attack for the most serious effects on agriculture. Aggregate crop survival should slowly increase for attacks occurring after this month, until after harvest--in October or November, say--when net crop loss may be only half that in June. Survival should thereafter fall again gradually and irregularly until the next June. Results will be much more sensitive if one looks at just one crop, particularly if in just one region where the planting and harvest dates are tightly clustered. Sensitivity of the survival of fruits and vegetables to date of attack might be expected in such circumstances.

Sensitivity to Foliar Contamination Parameters

The vulnerability model for crop plants under exposure to fallout radiation takes into account both external gamma and external beta radiation. Because gamma radiation is so penetrating, the exact distribution of the fallout on and around the plants is of little importance in calculating the gamma dose. The attenuation of beta radiation by air and tissue, however, suggests that this distribution may well be important in computing the beta contribution to the dose. A relatively simple model was used in 1967; the fallout was partitioned between a plane at the surface of the ground and one midway between the ground and the terminal meristems of the plants. The height of the latter plane was determined as a function of the age of the plant, and the partition depended on the foliar density, also a function of plant age. The plant was considered to be a vertical cylinder of tissue with radius and height dependent on age and with the sensitive volume at the top center of the cylinder.

Recent analyses of data from Operation Ceniza-Arena[2] suggest that the distributions might be considerably different both in geometry and in magnitude. In particular, the shape of the foliar canopy appears to affect the results, as does the condition of the leaves upon deposition (wet or dry). Rather than attempt to include these detailed dependencies in the computational models, the sensitivity of the total dose estimates to the values of the parameters and the geometry of the distribution were tested. The original equation for the total/gamma dose ratio was

$$R_{t\gamma} = 1 + f_{\ell}\, R_{\beta\gamma}(h/2) + Q_{\beta}(1-f_{\ell})\, R_{\beta\gamma}(h) \qquad (1)$$

Where 1 is the contribution from gamma radiation, $R_{\beta\gamma}$ is the ratio of beta to gamma dose, a function of h, the height of the meristems; r_1, the radius of the plant stem; and t_a, the time of arrival of the fallout. (The dependence of $R_{\beta\gamma}$ on r_1 and t_a is suppressed in Equation 1.) The quantity f_{ℓ} is the fraction of the fallout retained on foliage, and Q_{β} is the soil roughness attenuation factor for beta radiation from fallout on the ground.

The ratio $R_{\beta\gamma}$ was estimated by a line-of-flight attenuation method, but has been re-estimated by a pseudo-source method.[3] The new method (Table 2) shows increases in $R_{\beta\gamma}$ up to twice the figure obtained by the old method for small h and large r_1. Only for small r_1 and very large h did the old method predict higher $R_{\beta\gamma}$ than the new. The new results were also fitted by simple functions of h, r, and t_a, giving

Table 2

BETA/GAMMA DOSE RATIOS

Time of Arrival (hr)	Radius of Cylinder (cm)	Height of Dose Point (cm)					
		0.3	1.0	3.0	10	30	100
	0.1	57.30	45.78	35.62	23.96	15.19	6.03
0.25	0.3	25.38	20.92	16.62	12.11	8.10	3.98
	1.0	2.58	2.33	1.89	1.44	1.05	0.63
	0.1	55.93	44.56	34.55	23.15	14.45	5.53
1	0.3	22.87	18.82	14.95	10.88	7.26	3.56
	1.0	2.26	2.04	1.65	1.26	0.92	0.55
	0.1	50.35	39.95	30.79	20.55	12.43	4.44
4	0.3	17.63	14.50	11.51	8.37	5.57	2.71
	1.0	1.62	1.46	1.18	0.90	0.66	0.40
	0.1	41.58	32.76	25.04	16.50	9.57	3.01
16	0.3	11.12	9.10	7.20	5.21	3.44	1.63
	1.0	0.90	0.81	0.66	0.50	0.37	0.22

$$R_{\beta\gamma} = \frac{A_1}{1 + A_2\ t_a} \tag{2}$$

where
$$A_1 = \frac{A_3}{1 + A_4\ h} \tag{3}$$

$$A_2 = A_5 + A_6\ h \tag{4}$$

$$A_3 = 57.93\ e^{-3.405\ r_1} \tag{5}$$

$$A_4 = 0.02294\ r_1^{-0.464} \tag{6}$$

$$A_5 = r_1\ /\ (3.101 + 3.790\ r_1) \tag{7}$$

$$A_6 = 10^{-5}\ (-3.899 + 3.956/r_1) \tag{8}$$

These equations lead to an underestimate for large $R_{\beta\gamma}$, but it is felt that such large ratios would be experienced only under fairly unusual circumstances and that the estimating equation is adequate for most purposes.

The fallout distribution model as represented by Equation 1 is shown in Figure 3, part a. Parts b - f show other distributions that are considered as variants. Part b is part a with $f_\ell = 0$, and c is the same with $f_\ell = 1$. Part d represents an extreme where all the contamination concentrates near the meristem, and part e is a variation on that theme. Part f is probably the most realistic representation of a volume source, and corresponds to an equation

$$R_{t\gamma} = 1 + \left(1-f_\ell\right) Q_\beta\ R_{\beta\gamma}\ (h)$$
$$+ \frac{f_\ell}{4}\left[R_{\beta\gamma}\left(\frac{3h}{4}\right) + R_{\beta\gamma}\left(\frac{h}{2}\right) + R_{\beta\gamma}\left(\frac{h}{4}\right) + R_{\beta\gamma}\left(0\right)\right] \tag{9}$$

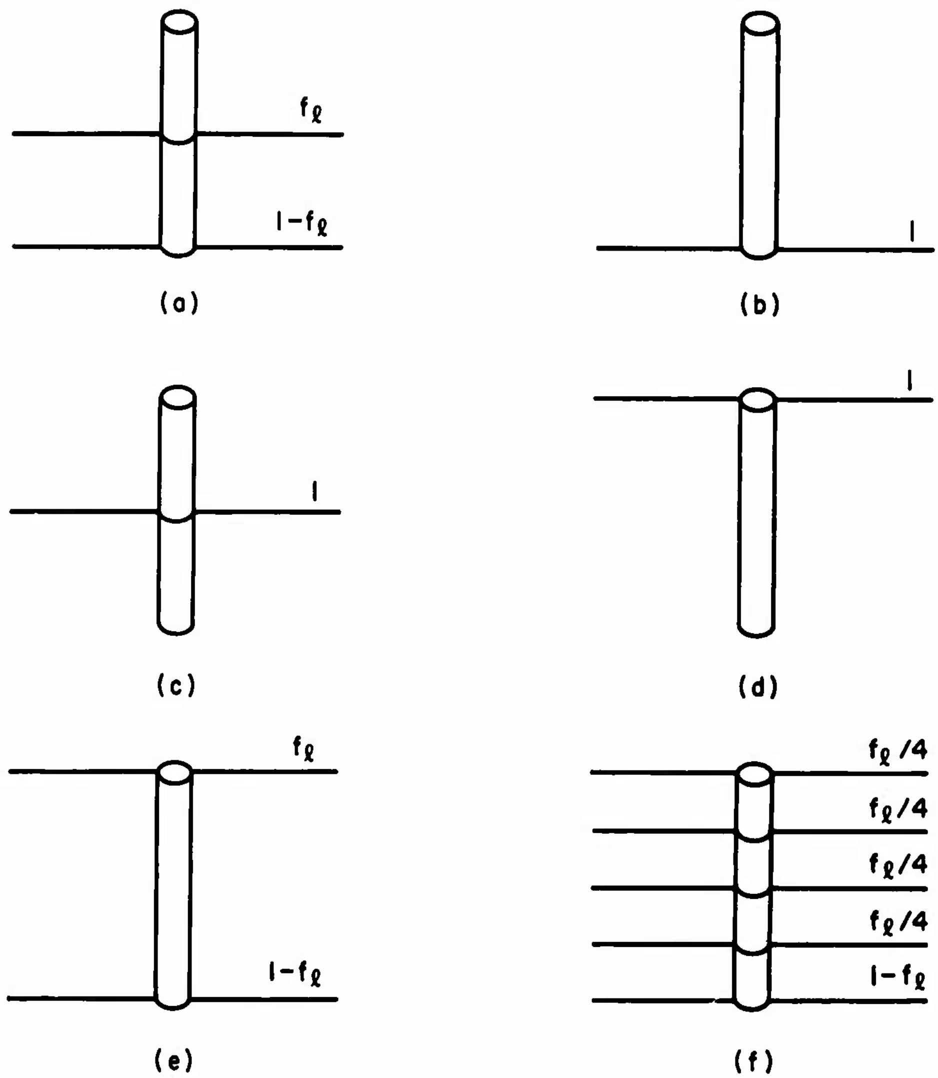

FIG. 3 FOLIAR CONTAMINATION DISTRIBUTION

The ratios $R_{t\gamma}$ were calculated for the models a - f and for the parameter values shown below:

h(cm)	r_1(cm)	f_ℓ	Q_β
0.3	0.1	0.01	0.1
1.0	0.3	0.03	0.2
3.0	1.0	0.10	0.5
10.0		0.30	
30.0		1.00	
100.0			
300.0			

t_a (hr)
1
16

The estimates were always in the order $R^d \geq R^e \geq R^f \geq R^a \geq R^b$, and with $R^d \geq R^c \geq R^a$. The d, e, c, and f models reached 34.2, 11.7, 8.44, and 3.81 times the a model, respectively, for extremes of the parameters, while the b model was as low as 0.11 of the a model. Models b - e seem sufficiently unrealistic that the remaining question is how well model a represents the situation f. Models a and f match to within a factor of 2 for all but 9 of the 630 combinations, of parameters, and within 10 percent for the majority of cases. The non-matching sets of parameters are somewhat unusual combinations.

The effect of varying the parameters f_ℓ and Q_β can be seen in Figure 4. In the extreme case where h = 0.3 cm, r = 0.1 cm, and $Q_\beta = 0.1$, the estimate of $R_{t\gamma}$ can vary by a factor of 8 as the value of f_ℓ ranges over a factor of 100, but only by a factor of 2 when $Q_\beta = 0.5$. Variations are also less marked for larger r_1 or h. On the other hand, the estimates are approximately linear with Q_β if f_ℓ is small, but independent of Q_β when f_ℓ approaches unity. Misestimation of Q_β and f_ℓ are thus unlikely to cause errors in $R_{t\gamma}$ larger than a factor of two.

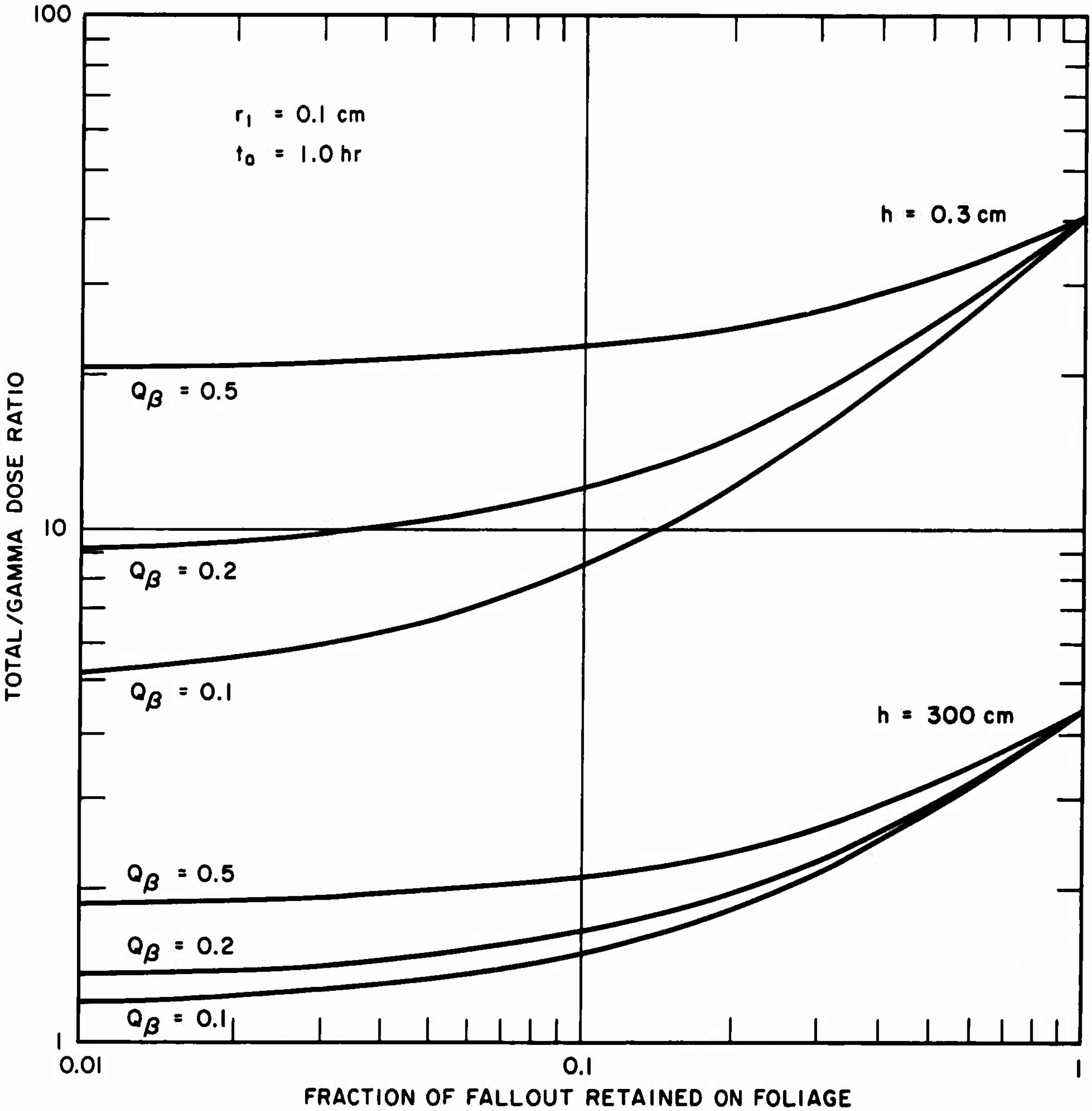

FIG. 4 VARIATION OF THE TOTAL/GAMMA DOSE RATIO

Thus, the possible sources of error that have been identified--in the foliar contamination model, in the beta/gamma dose ratios, in the foliar retention fractions, and in the beta soil roughness factor--are independently unlikely to make differences in the total gamma dose ratio, and therefore in the total dose estimate, of more than a factor of two. It is also unlikely that several of these uncertainties would be acting simultaneously in the same direction, so that a rather conservative assumption would be that all doses should be increased by a factor of two. This is equivalent to reducing the lethal dose criterion, D_{ℓ}, by a factor of two in the damage assessment program.

A sample of the effects of such an assumption are shown in Table 3, also for Region 6. If the crop was not vulnerable to radiation at the time of attack, as with sorghum, no effect is shown. Even for crops near their peak sensitivity, for example, spring wheat or spring barley, the factor of two dose difference only changes net crop loss by 15 percent and net crop survival by less than 10 percent for this type of attack (SRI B). The lack of sensitivity exhibited arises from the dispersed nature of agricultural resources; very few acres of any crop are in just such fallout areas that a factor of two in the dose makes a difference. Most acreage, in fact, is subjected to essentially no fallout in attacks of the magnitude usually considered. Therefore, although better information is of course desirable on the foliar contamination inputs, the results for crop survival are not likely to change drastically.

Sensitivity to Vulnerability Criteria

Another group of parameters that can be questioned are the criteria against which crop and livestock vulnerability are measured. These include the lethal dose for mature plants, the dependence of yield on dose for doses less than lethal, the possibility of lower lethal or yield-reducing doses if delivered to plants at especially sensitive stages of

Table 3

EFFECT OF DOSE ESTIMATE ON CROP VULNERABILITY
Region 6--June 15

Crop	Crop Code	Net Survival Percent (standard assumption)	Net Survival Percent (double dose assumption)*
Corn	21	90.7	90.2
Sorghum	22	92.5	92.5
Wheat, winter	23	67.5	62.2
Wheat, spring	24	66.6	61.5
Oats, spring	26	80.1	75.8
Barley, winter	27	80.4	79.5
Barley, spring	28	61.0	56.4
Rice	29	100.0	100.0
Soybeans	32	94.2	94.2
Alfalfa	42	88.3	86.9
Potatoes	50	71.2	71.2
Sugarbeets	56	77.5	75.0
Sweetcorn	62	73.2	69.4
Animal calories		88.2	87.2
Human calories		72.7	68.7
Total calories		83.6	81.0

* Lethal dose = 1/2 lethal dose standard.

growth, and the median lethal doses for farm animals. There has been a scattering of new results since early 1967 that suggests, for instance, a reduced lethal dose for sheep, reduced lethal doses for certain crop plants, especially in early stages of reproductive growth, and dependencies of yield on dose that might not fit our logarithmic assumption.[1]

In view of the discussion of the above section, we have not seen fit to pursue these questions in any detail. Rather, the sensitivity analysis shown in Table 3 is equally applicable to a reduction in the lethal dose criteria by a factor of two. A similar reduction in livestock lethal doses would probably show similar results, for again the fraction of all livestock in fallout areas with doses between LD_{50} and $LD_{50}/2$ must not be very large; we shall have more to say about the dispersion of livestock in a later section. Thus, only very startling changes in the vulnerability criteria can change the vulnerability results by significant factors.

III AGRICULTURAL PRACTICES

A number of agricultural practices exist that were not considered in previous NESS studies and that are difficult to incorporate into computational models. It is clear, however, that some of these practices--the application of fertilizer and the use of petroleum for farm machinery, for example--are extremely important to U.S. agriculture and that, without them, the character of the agriculture system would be remarkably different.

A selected group of agricultural practices was therefore studied for the purpose of discovering how important their roles were in agricultural production. The methodology was essentially an abbreviated form of that used in a previous study by the Institute,[5] but was conducted independently because it has been almost a decade since these considerations have been reviewed. The agricultural practices were investigated without regard to interactions, with the goal of identifying any characteristics that might be a potential vulnerability for the agricultural system. A summary of the practices studied and the most pertinent results is shown in Table 4.

Fertilizer

Fertilizer is used on nearly two out of three farms. The proportion of farms using fertilizer is much higher in both the Northeast and the Southeast than in the West. The land fertilized in 1964 totaled over 150 million acres,[4] equivalent to 18 percent of all acreage in crops, and pasture, exclusive of woodland pasture. The distribution by crop of acres fertilized was as follows:[4]

Table 4

AGRICULTURAL PRACTICES AND POSTATTACK PRODUCTION

Practice	Potential Influence on Farm Productivity	Remarks
Fertilizers	• Serious effect on crop yields possible • Up to 50% reduction of main food and feed grains • Similar results for other crops	Loss of feed grains would have implications for livestock production
Pesticides	• Overall influence on production uncertain • Use on wheat and corn has been negligible in the past, but is increasing rapidly • Effects on potatoes, vegetables, and fruits large	Lack of pesticide application in one year may lead to pest population explosion in following year
Irrigation and cultivation	• Little effect on main food and feed grains • Essential to high yields of rice, sugar beets, potatoes, alfalfa, vegetables, and fruits	Losses of alfalfa and sugarbeets might have effects on livestock feeding
Petroleum	• U.S. agriculture highly dependent on petroleum	No feasible alternatives
Electricity	• Corn and wheat insensitive; livestock, poultry and dairy production highly dependent	Generators use petroleum
Cattle feedlots	• Increasing in size and importance, but still dispersed	Included in "Farm" inventory
Poultry raising	• Increasingly automated and concentrated • May eventually be vulnerable	Included in "Farm" inventory

Hay and Cropland Pasture	11.4%
Other Pasture	4.3
Corn	33.2
All Other Crops	51.1

Table 5 gives data on fertilizers used on the most important crops in U.S. agriculture. More fertilizer is used on corn, the principal feed grain, than on any other crop. For those crops listed, corn required 1,850,000 tons of fertilizer compared to 2,300,000 tons for all other crops combined. Nearly 80 percent of corn acres were fertilized in 1964.[6,7]

On the basis of acres fertilized, wheat ranked second. As the main food grain, wheat required about 660,000 tons of fertilizer on about 55 percent of the acres harvested. The third ranked consumer of fertilizer was sorghum, with about 7.4 million acres, or 50 percent of the total harvested acres, fertilized. Counting fertilization of pastures, sorghum accounted for only 2 percent of all fertilizer used.[6,7]

The importance of fertilizers for the production of sugarbeets, potatoes, rice, vegetables, and fruits is reflected by the percentage of acres fertilized; the first three were nearly 100 percent fertilized, with vegetables 90 percent and fruits 80 percent. The rates of fertilizer application are also highest among these crops--potatoes, 270 pounds/acre; fruits, 223 pounds; vegetables, 214 pounds; sugarbeets, 192 pounds; and rice, 126 pounds. On a rate basis, corn (120 pounds) and wheat (70 pounds) both lag.[6,7]

Common practice usually applies fertilizers at or before the time of sowing.[8] With corn, however, only 60 percent of the acres receive fertilizer before seeding,[9] and with winter wheat only 25 to 35 percent at sowing time, the rest being applied as topdressing during the following spring or summer.[10] For those crops that are fertilized at planting time, the lack of fertilization caused by fallout would have no added effect on

Table 5

FERTILIZERS USED ON CROPS
(1964)

Crop	Acreage Harvested	Acreage Fertilized	Plant Nutrients Used (tons)	Rates per Acre Receiving (pounds)			Total Rate Receiving (pounds)
				N*	P*	K*	
Corn	63,512,263	50,772,842	2,850,995	64.0	20.4	35.5	119.9
Sorghum	15,036,100	7,434,354	300,107	71.0	11.1	17.7	99.8
Wheat	47,962,744	26,012,571	633,766	33.4	13.2	23.9	70.5
Oats	18,458,863	6,007,053	160,016	22.6	15.1	29.5	67.2
Barley	10,086,618	4,874,237	124,115	39.2	14.0	19.4	72.6
Rice	1,812,290	1,777,540	86,720	74.2	19.0	32.6	125.8
Soybeans	30,253,128	6,218,943	159,093	9.9	14.9	36.0	60.8
Alfalfa (seed)	100,340	46,378	599	39.7	27.4	35.1	102.2
Potatoes	1,265,350	1,241,891	145,629	106.4	54.5	110.4	271.3
Sugarbeets	1,374,234	1,381,943	101,594	112.0	42.5	37.9	192.4
Vegetables	3,382,324	3,000,888	281,528	91.0	43.0	79.7	213.7
Fruit	4,341,461	3,591,199	284,248	95.5	34.7	93.0	223.2

* N = nitrogen
P = phosphorus
K = potassium

Source: Reference 5.

loss of crop. If, however, these crops were not fertilized early, the expected yield after a winter attack might be reduced.

More information on the potential vulnerabilities posed by fertilizer practices can be inferred from Figures 5 and 6. These show examples of crop yield response to fertilization for corn and wheat and illustrate how the amount of fertilizer applied influences the yield. The two curves in each figure represent the crop yields in bushels per acre as a function of the pounds of the leading fertilizer applied per acre,* for two different ASRs (agricultural subregions). The difference in response is due to the different soil, climate, and other factors. Also shown are the actual fertilization rate and yield for 1964, which demonstrate that responses for specific years can differ appreciably from the expected curve. The deviation for corn in ASR 25 (50 bushels per acre observed compared with 75 bushels per acre expected) seems to be an extreme, and other comparisons show closer agreement.[11]

Generalization of the fertilizer response was obtained by aggregating data for individual ASRs and is illustrated by Figures 7 and 8, expressed in terms of percent of maximum yield. The ranges of likely responses are shown to include different soils and climates. Notice that the saturation effect implies decreasing returns for high level fertilizer application and that farmers choose to apply only between 25 and 50 percent of the fertilizer for maximum yield.

Even though farmers do not currently use maximum rates of fertilizer, the loss of fertilizer could have serious implications for U.S. agriculture. Not only are most acres of corn fertilized, but also corn has a very exhausting effect on the soil, and it is only by supplying the necessary nutrients in the correct proportions that satisfactory crops can be

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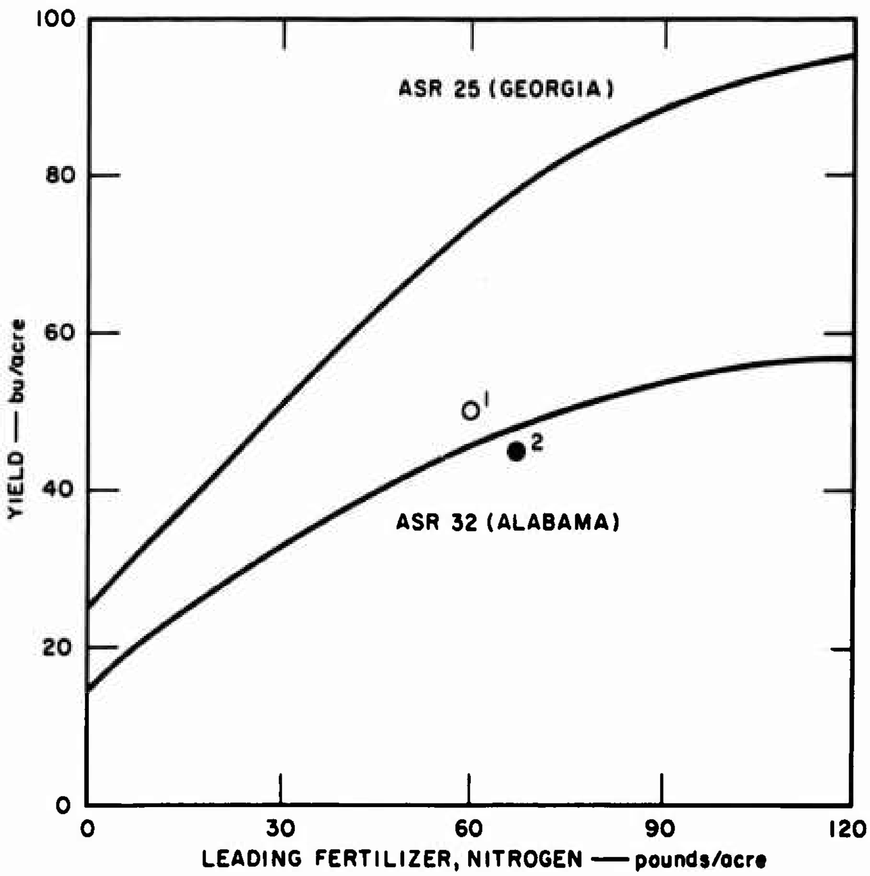
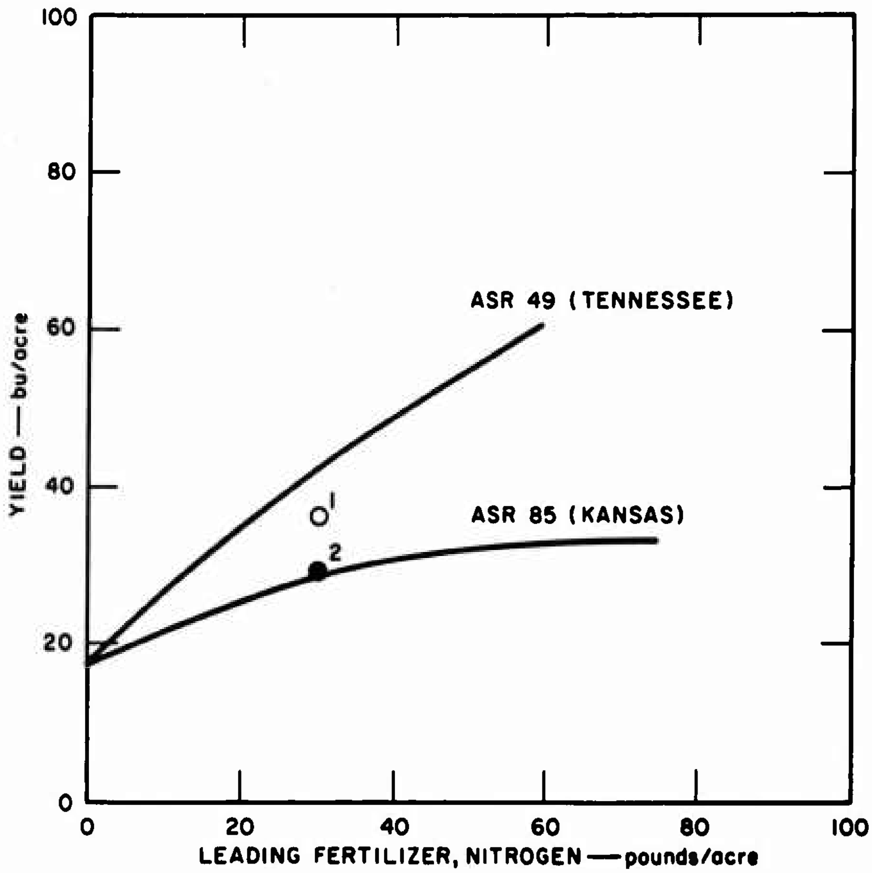
* The nutrient to which the yield response is greatest; for most crops it is nitrogen.



1 Actual fertilizer rate and crop yield 1964 in ASR 25.
2 Actual fertilizer rate and crop yield 1964 in ASR 32.

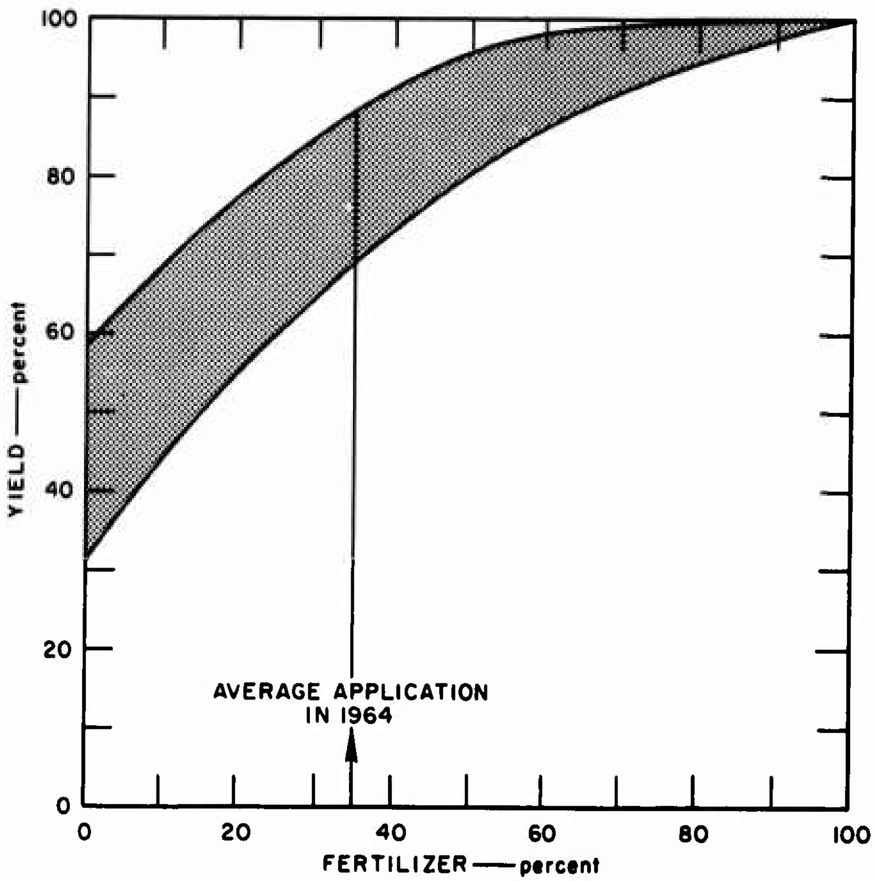
SOURCE: Ref. 10

FIG. 5 CROP YIELD RESPONSE TO FERTILIZER – CORN



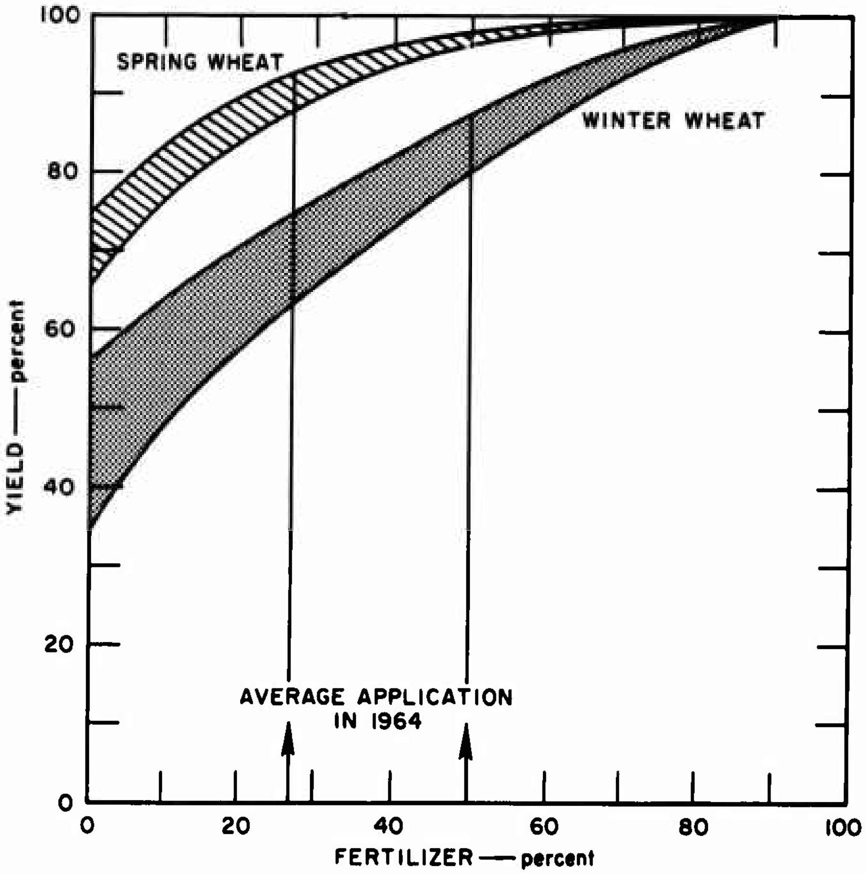
1 Actual fertilizer rate and crop yield 1964 in ASR 49.
2 Actual fertilizer rate and crop yield 1964 in ASR 85.
SOURCE: Ref. 10

FIG. 6 CROP YIELD RESPONSE TO FERTILIZER – WHEAT



SOURCE: Stanford Research Institute and Ref. 10.

FIG. 7 AGGREGATE CROP YIELD RESPONSE TO FERTILIZER – CORN



SOURCE: Stanford Research Institute and Ref. 10.

FIG. 8 AGGREGATE CROP YIELD RESPONSE TO FERTILIZER – WHEAT obtained. Without fertilizer, the harvest could drop from about 80 percent of the maximum attainable yield to about 45 percent, thereby reducing the total production from 4.1 billion bushels to 2.3 million, or around 55 percent. This reduction would, in turn, affect the size of livestock herds that could be maintained.

Wheat also removes considerable amounts of nutrients from the soil, and a fertilization of about 25 pounds per acre is practiced. The total production of wheat, normally at about 85 to 90 percent of the maximum possible, might drop to 50 percent with no fertilization. The corresponding total production ratio is 765 million bushels to 1,300 million bushels, or under 60 percent.

Since potatoes, fruits, vegetables, and other important crops are even more heavily fertilized, large reductions in yield could be expected there too.

A possible mitigating factor in the first year after attack might be that extra animals would have to be slaughtered because of the feed deficit and, thus, the available meat would partially offset the grain and vegetable shortage. However, the only reasonable substitute for fertilizer is more extensive agriculture, using poorer land less efficiently with correspondingly heavier manpower and equipment demands.

It was beyond the scope of this research to investigate the likelihood of extensive losses in the production and application of fertilizers. A few qualitative remarks are made here only for perspective. Production of fertilizer is classified under SIC* 28, Chemicals and Allied Products. Although fertilizer manufacturing is probably more dispersed than chemicals, if

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* Standard Industrial Classification.

we assume that the chemical industry is representative of fertilizer manufacturing, 50 percent of the capacity (as measured by MVA, i.e. Manufacturing Value Added) is concentrated in 10 metropolitan areas[12] or, if inventoried in a grid with five-kilometer spacing, in 165 squares.[13] This concentration and vulnerability is slightly greater than, say, the food processing industry, but less than the petroleum refining capacity or transportation equipment manufacturing. The same metropolitan areas or five-kilometer squares, of course, do not necessarily appear in the same order in all industrial lists. Therefore, attacks that hit one industry heavily may hit another quite lightly. But unless an attack is specifically directed at one sector of the economy, damage assessments usually predict a fairly even distribution of damage over the sectors. For attack SRI B, for instance, chemicals experience about 50 percent survival (undamaged plus light damage), whereas other sectors survive from 35 to 70 percent.[14] A 50 percent survival of the fertilizer industry would imply that agricultural losses because of fertilizer shortages would be no more than 20 percent, rather than the 40 percent loss that would be possible if all fertilizer were unavailable. Application of fertilizer might be an additional problem if petroleum shortages caused curtailment in the use of farm machinery. (This point will be seen to apply to several agricultural practices and will be discussed again in the petroleum section.)

Pesticides

Pesticides can be grouped into three major categories according to their use:[8,15]

1. Fungicides: Chemicals that kill or inhibit fungi
2. Herbicides: Chemicals that kill or inhibit the growth of plants
3. Insecticides: Chemicals that kill or inhibit the development of insects

Forty-two percent of all pesticides produced in the United States in 1964 were used by U.S. farmers. The consumption for farm use has increased rapidly in recent years. One measure of this trend is the amount spent by farmers on pesticides. This amount tripled between 1954 and 1964.[16] In 1964, 458 million pounds of pesticides and an additional 313 million pounds of petroleum were used as pesticide material; 93 percent of this total was used on crops.[15]

One hundred seventy million pounds of fungicides were applied, mainly on miscellaneous field crops and citrus in the Southeast and fruits in the Pacific regions. Sulfur is the leading fungicide. Of the herbicides used in 1964, 90 percent were applied on crops, and the total amount used was 84 million pounds. The most popular herbicide product is "2,4-D." Insecticides are the major class of pesticide used by farmers--156 million pounds in 1964. The most commonly used are Toxaphene, Lindane, and DDT. Fifty percent of the crop insecticides were used on cotton, and only 10 percent for the control of corn pests.[15]

A large amount of petroleum--of the order of 50 million gallons--was also used by farmers as an active pesticide material. Most was used in herbicidal and insecticidal preparations. Seventy-five percent, or well over 200 million pounds, was used on crops, mainly on cotton, hay, pasture, rangeland, other forage crops, and citrus.[15]

There are, in addition, a number of miscellaneous pesticide materials accounting for 13 percent of the total consumption. Among them are fumigants, defoliants and desiccants, growth regulators, and miticides, none of which play a significant role in the major feed and food crops.

Insect and disease control is practiced on about 10 percent of the cropland and pasturelands, with weed control on 6 percent of the acreage. For corn, on the other hand, only 6 percent is treated with pesticides for insects and diseases, but 28 percent receives some sort of weed control herbicide treatment.* Weed control is also practiced on about 20 percent of small grain acreage. For vegetables and potatoes, insect and disease control can be highly important; 74 percent of vegetables and an even higher percent of potatoes receive treatment.[15,17]

The use of pesticides by crop is shown in Table 6. The variation in use practices by region of the United States is indicated by Table 7. The geographical variation for insect and disease control is quite marked--1.4 treatments per year in the Northern Plains compared with 5.3 in the Delta states. Weed control is unsurprisingly more consistent and occurs about once a year in all regions. Similar variations occur between crops as shown in Table 8, with most frequent treatment of potatoes, vegetables, and fruits with insecticides and fungicides. The kinds of equipment used for applying the pesticides are shown in Table 9.[18]

The implications of these statistics for the vulnerability of agriculture to nuclear attack are not obvious. The fact that the major field crops can be successfully grown without pesticides in many places suggests that the unavailability of pesticides might not be as serious as one would initially suspect. However, the application of pesticides contributes to the stability of crop production over the years, and the loss of pesticides in one year might allow considerable growth in the insect population, which could affect the situation much more the following growing season. Any losses of pesticide availability would also obviously be much more strongly felt in the yields of potatoes, fruits, and vegetables. Furthermore, substitutes for the application of insecticides and fungicides are rare even though cultivation is an alternative to herbicides for weed control. On the balance, however, assuming again that pesticide production is correlated with the chemical industry and is of no more than

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* Note added in proof: These figures apparently have increased markedly since 1964, implying an increasing preference for pesticides over other cultural practices.

Table 6

QUANTITIES OF PESTICIDES USED ON SELECTED CROPS
(Thousands of pounds)
1964

	Fungi-cides	Herbi-cides	Insecti-cides	Other Pesti-cides	Petro-leum
Corn	543	25,476	15,668	76	1)
Sorghum	1)	1,966	1)	1)	1)
Wheat	1)	9,178	1)	1)	1)
Other grains	1)	9,119	1)	1)	1)
Soybeans	1,272	4,208	4,997	1)	5,996
Other field crops	54,214	11,206	12,551	1,611	1,682
Hay and pasture	1)	4,687	1)	1)	48,435
Potatoes	3,719	2)	1,456	91	3)
Other vegetables	6,993	2)	8,290	5,819	5,972
Fruit	86,386	2)	16,729	3,617	112,916
Fruit and vegetables	-	5,846	-	-	-
Other crops	12,816	4,628	83,493	29,982	57,560
Total	165,943	76,314	143,184	41,196	232,561

1) Included in other field crops

2) Included in fruit and vegetables

3) Included in vegetables

Source: Reference 15.

Table 7

EXTENT OF PEST CONTROL BY REGIONS
(Average Times Treated)
1952 and 1958

REGION	INSECT AND DISEASE CONTROL		WEED CONTROL		TOTAL TREATMENT	
	1952	1958	1952	1958	1952	1958
Northeast	5.13	4.45	1.07	1.05	3.26	2.52
Lake States	4.22	3.10	1.07	1.05	1.64	1.35
Corn Belt	1.96	1.54	1.08	1.01	1.25	1.12
Northern Plains	1.44	1.35	1.03	1.02	1.07	1.10
Appalachian	2.97	2.79	1.11	1.07	2.56	2.12
Southeast	3.53	3.87	1.37	1.01	3.40	3.21
Delta States	3.71	5.27	1.16	1.04	3.38	3.38
Southern Plains	1.98	2.78	1.04	1.07	1.77	2.21
Mountain	2.03	1.56	1.04	1.01	1.36	1.28
Pacific	2.35	2.54	1.19	1.07	1.77	1.75
48 States	2.86	2.61	1.08	1.03	1.94	1.65

Source: Reference 18.

Table 8

EXTENT OF PEST CONTROL BY CROPS
1958

A. INSECT AND DISEASE CONTROL

CROP	AVERAGE TIMES TREATED
Corn	1.08
Other Crops	1.42
Alfalfa	1.27
Potatoes	5.12
Vegetables	3.25
Fruits and Tree Nuts	4.55

B. WEED CONTROL

CROP	AVERAGE TIMES TREATED
Corn	1.05
Small Grains	1.04
Other Crops	1.37
Pasture and Rangeland	1.14

Source: Reference 18.

Table 9

DISTRIBUTION OF ACREAGE TREATED*
1958

Size of Farm (Acres)	Percentage Treated with	
	Air Equipment	Ground Equipment
Less than 50	5.2	94.8
55 to 99	8.0	92.0
100 to 179	11.3	88.7
180 to 259	13.4	86.6
260 to 499	19.4	80.6
500 to 999	30.7	69.3
1000 and over	45.1	54.9

* For Pest Control and Defoliation.

Source: Reference 18.

average vulnerability, the pesticide application practices in use today probably imply only a moderate vulnerability of the U.S. agricultural system.

Irrigation and Cultivation

Irrigation makes the difference between agriculture and no agriculture in many arid regions of the United States. In 1964, irrigated lands totaled 37.1 million acres, regionally distributed as follows:[4]

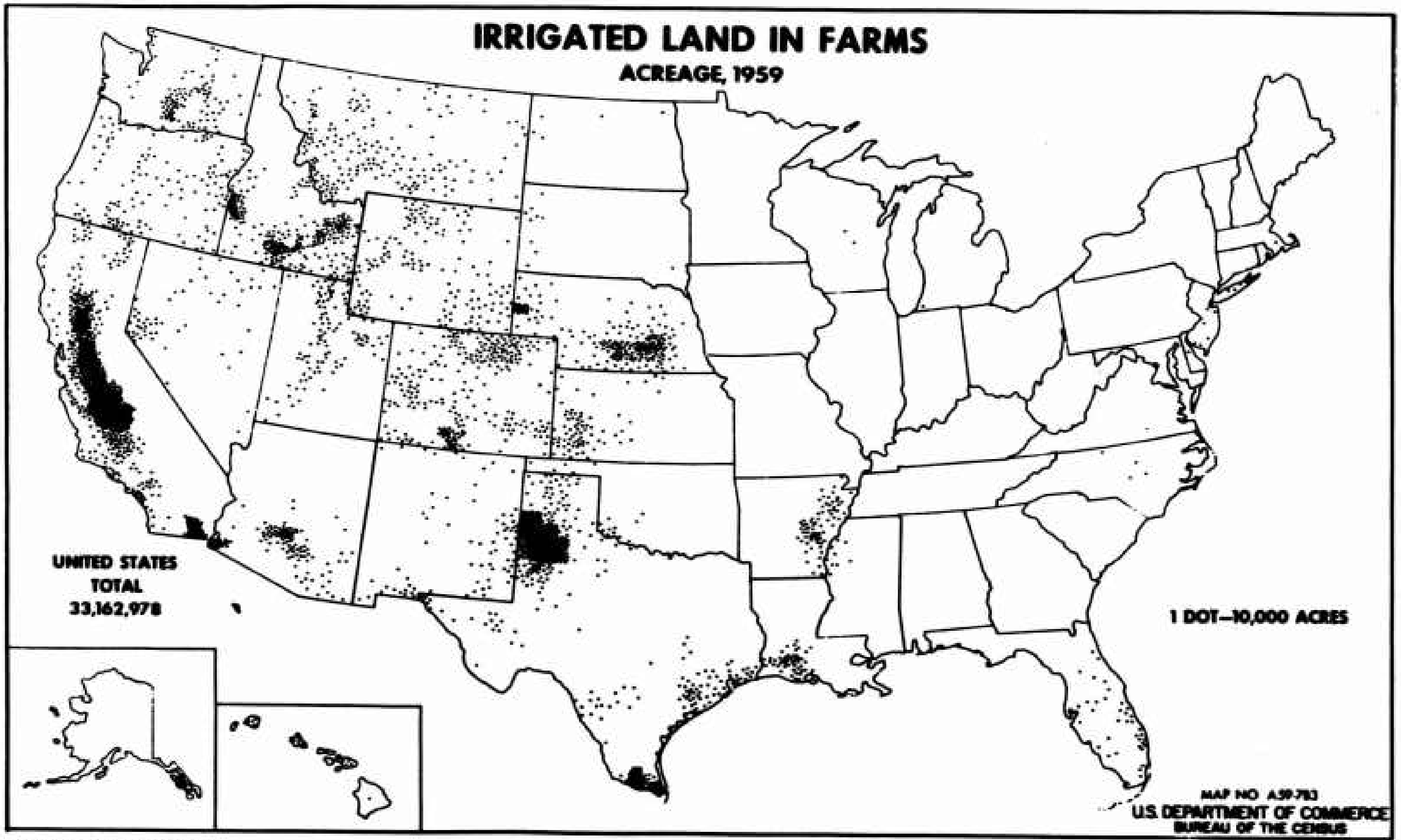
11 Western States and Hawaii	23.3 million acres
6 Great Plains States	10.0 " "
31 Eastern States	3.8 " "

Figure 9 shows this distribution;[19] irrigation was therefore practiced on about 8 percent of the total acreage of cropland. The distribution by use is primarily on cropland as opposed to pasture:

Cropland Harvested	30.8 million acres
Pasture or Grazing	5.5 " "
Other Cropland Uses	0.8 " "

The extent of irrigation for selected crops is presented in Table 10. Very low percentages of the acreage harvested of the main food and feed grains (corn and wheat) are irrigated. Irrigation is, of course, mandatory for rice, and appears to be almost so for sugarbeets; 80 percent of the latter are irrigated. Irrigation is also very significant for the production of potatoes, vegetables, fruits, and alfalfa. About half of the acreage harvested for each of these crops was irrigated.

Irrigation requires relatively large amounts of labor in the preharvest stages and, thus, may be sensitive to potential losses or denial of labor. Table 11 shows national average preharvest labor requirements per acre for selected crops irrigated and nonirrigated. The inferred labor for irrigation is also shown. Most crops are irrigated by sprinkler and show large irrigation labor factors. Potatoes are commonly irrigated



SOURCE: Ref. 18

FIG. 9 IRRIGATED LAND IN FARMS

Table 10

ACRES HARVESTED FROM IRRIGATED LAND

Crops	Total Acres Harvested	Acres Harvested From Irrigated Land	% Harvested From Irrigated Land
Corn	63,514,906	2,428,000	3.8
Sorghum	14,965,707	3,377,778	22.5
Wheat	47,958,362	1,963,525	4.1
Oats	18,935,713	300,039	1.6
Barley	9,805,327	1,503,666	15.3
Rice	1,815,013	1,815,013	100.0
Soybeans	30,351,248	427,206	1.4
Alfalfa	675,009	282,038	41.8
Potatoes	1,173,918	608,880	51.9
Sugarbeets	1,376,026	1,099,481	80.0
Vegetables	3,333,772	1,543,821	46.3
Fruit	4,412,267	2,275,186	51.6

Source: Reference 4 .

Table 11

LABOR USED FOR IRRIGATION OF SELECTED CROPS

	Preharvest Man-Hours for Nonirrigated Acre	Preharvest Man-Hours Per Irrigated Acre	Man-Hours Per Acre For Irrigation
Corn	5.2	9.4	4.2
Sorghum	2.8	8.4	5.6
Wheat	1.7	5.6	3.9
Oats	2.0	7.3	5.3
Barley	1.5	6.8	5.3
Alfalfa	1.0	9.3	8.3
Potatoes	21.0	21.0	-

Source: Reference 20.

by letting water into the ditches between rows, a low labor procedure, which may explain in part the indicated equality of irrigated and nonirrigated requirements. However, another factor is that the labor requirements for cultivation are higher in heavy rainfall areas where irrigation is unnecessary, thereby raising the national average for nonirrigated acreage. In similar areas of the country, labor requirements for irrigated crops are always slightly greater than for nonirrigated.[20]

Detailed information on crop responses to irrigation is difficult to obtain. Some very general figures, which may serve to indicate the magnitude of the effect on crop production expected, can be mentioned. A rule-of-thumb might be that irrigated crops yield two to three times as much as dry land crops.[21] Wheat and oats are less responsive, but sorghum is in this range with a factor of 2.5.[4] Rice, sugarbeets, and alfalfa all cannot be grown without adequate water, either from irrigation or heavy precipitation.

In summary, the denial of irrigation, in some cases even if for only a few days, could have serious effects on the production of certain crops. On the other hand, the principal food and feed crops are customarily not irrigated and are relatively invulnerable to such an effect. If irrigation were interrupted by loss of electricity for pumping or denial of labor by fallout, some alfalfa and sugarbeets might be lost, causing an additional burden on the animal feed supply. So again the problem of irrigation is more likely to affect the balance among different foodstuffs than the total food supply, with potatoes, fruits, vegetables, and the like in relatively shorter supply.

A closely associated group of agricultural practices is implied by the term cultivation. Although cultivation may include the application of pesticides and fertilizers, here only mechanical practices for loosening the soil and controlling weeds during the growing season are considered.

Various types of plows and hoes, usually machine operated, are used in these operations. The principal value of cultivation after seeding is for the destruction of competing weeds. Most cultivation is carried out early in the growing season when the crop is small relative to competing weeds, and mechanical cultivation is feasible.

Cultivation, under this definition, is feasible only for crops grown in well defined and separated rows. Small grains and rice are not ordinarily cultivated after planting. Alfalfa can be cultivated only for a short while after the harvest and before new growth is extensive. Sorghum is cultivated until the growth spreads, so that competing weeds have little chance in the shade of the foliage. It is important to cultivate corn but, again, this is impractical after the corn is about a foot high. Cultivation is widely practiced with potatoes and vegetable crops, in orchards, and with other fruits.

Quantitative relationships between cultivation and yield were not found. Qualitatively, competing weed growth can lead to a complete loss of the crop when, as in a wet year, cultivation cannot be carried out.[8] Small decreases in yield are to be expected for any missed cultivation. The principal reason for postattack cutbacks in cultivation would be fallout denial to farmers, although shortage of petroleum might be a factor. Because fallout areas that are dangerous but not lethal to farmers cover a relatively small fraction of the area of the country, cultivation denial where harvesting is possible should be relatively rare. Because many of the principal food and feed crops are also not particularly cultivation sensitive, it is doubtful that current cultivation practices imply a serious vulnerability of the agricultural system.

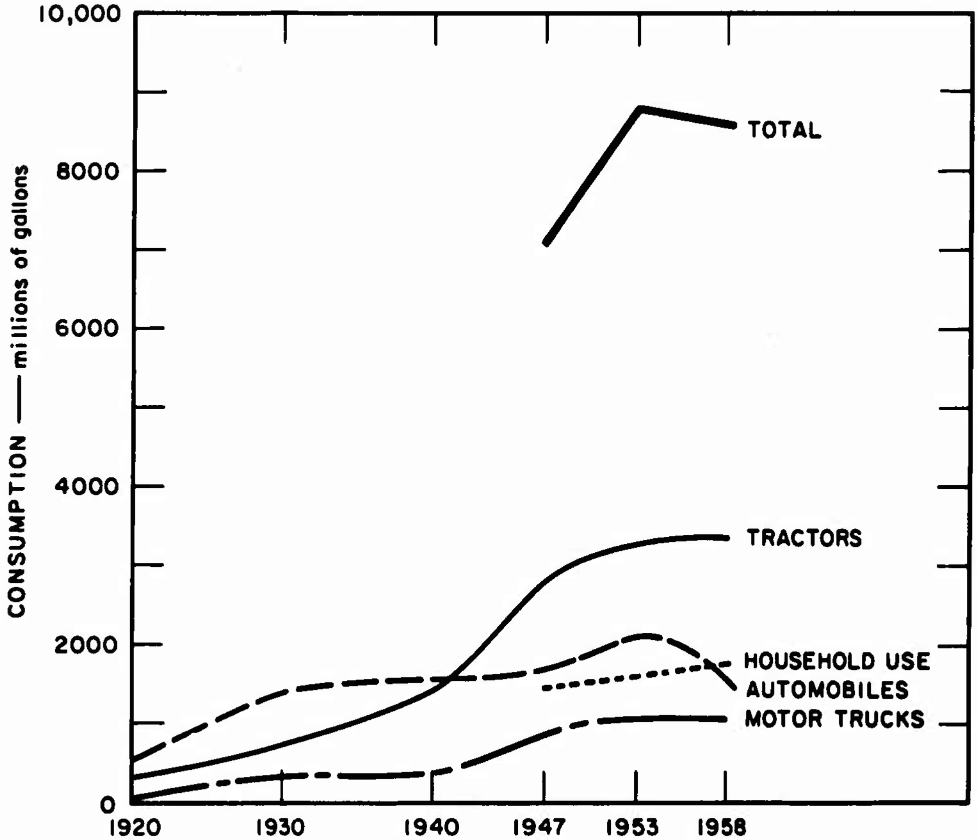
Petroleum

Farmers used about 8,610 million gallons of liquid fuel in 1959, representing around 10 percent of gasoline and diesel oil production in the United States. Of this total, around 70 percent were used for farm business, 20 percent for household consumption, and 10 percent for automobile use other than for farm business.[21] Fuel used for such purposes by different states ranged from 11 million gallons in Nevada to 746 million gallons in Texas. These quantities are influenced by (1) the number of petroleum-powered machines, (2) the average size of these machines, and (3) the average annual use of the machinery.[22]

Machines used for field work on farms are now powered almost exclusively by gasoline and other liquid petroleum fuels. Petroleum products are also used for drying crops, brooding chicks, killing weeds, and a variety of household purposes.[17]

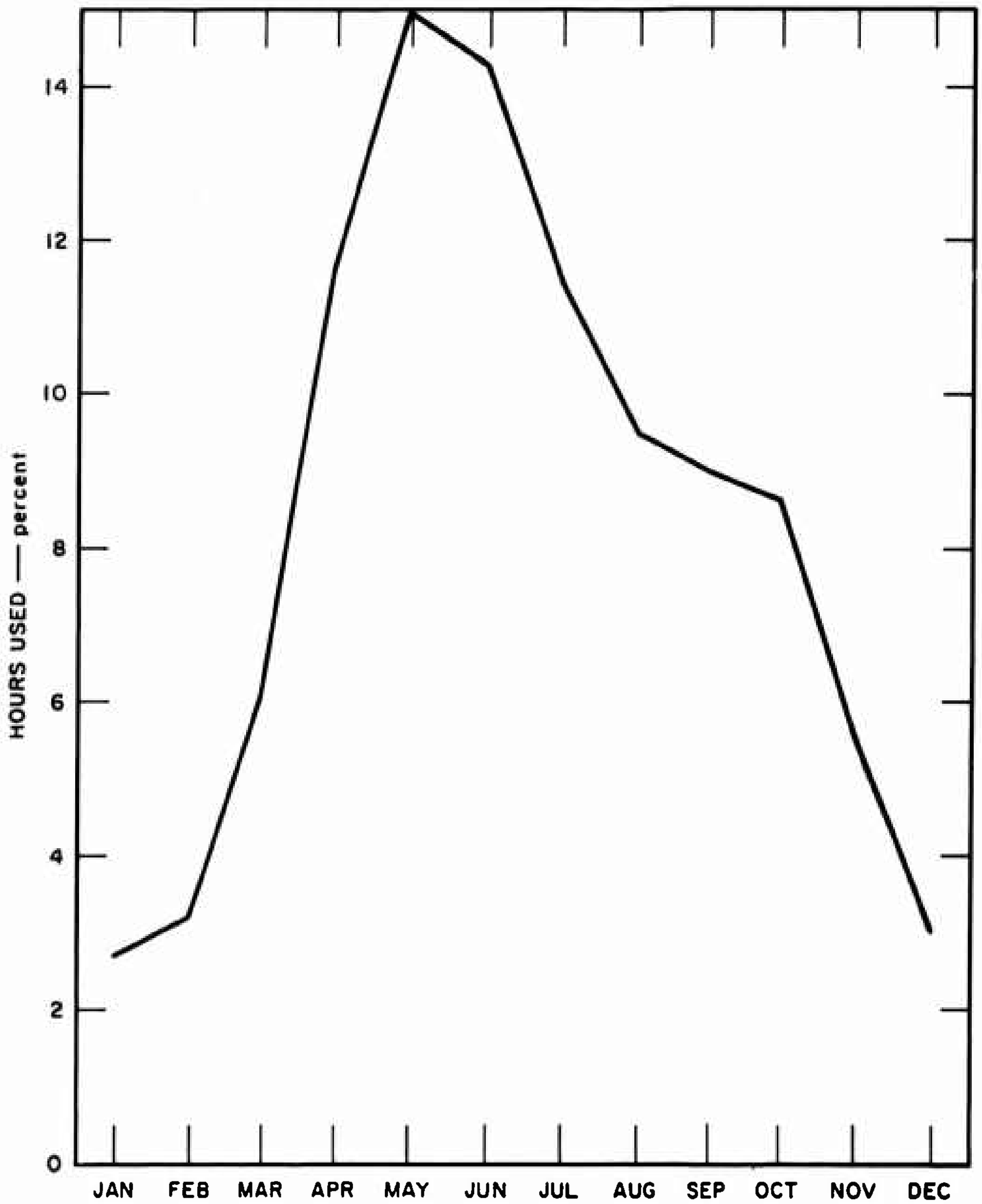
The average liquid petroleum fuel consumed per farm was 2,100 gallons in 1959. This figure appeared to be increasing in the years immediately before 1959, but the increase was certainly due in part to the declining number of small farms with resultant increased average farm size.[22] The total consumption of fuel in fact remained fairly stable, presumably because of the near attainment of full mechanization, and may be assumed to be increasing only slowly at the present time. These trends are illustrated in Figure 10, which also gives breakdowns by class of use (tractors, household, automobile, and motor truck).

In recent years tractors have accounted for about 50 percent of the motor fuel used by farmers for all purposes. Figure 11 indicates that tractor use is quite seasonal, being used principally for primary tillage, and it may be inferred that demands for motor fuels would be correlated closely. Therefore, four months--April through July--probably account for 50 percent of the annual tractor fuel bill, with May and June alone contributing 30 percent. The coldest winter months account for only 2 to 6 percent of the demands. Regional differences are relatively small, although March can see fairly extensive tractor use in many of the Southern states.



SOURCE: Ref. 21

FIG. 10 FARM CONSUMPTION OF LIQUID FUEL



SOURCE: Ref. 21

FIG. 11 PERCENTAGE OF TRACTOR USE DURING THE YEAR

Without attempting quantitative analyses, we can state immediately that without petroleum, field crop production is virtually impossible in the United States system. All major food and feed crops are mechanically planted and harvested. In addition, as has already been discussed, the application of fertilizers and pesticides and cultivation also depend on petroleum-fueled machinery. Truck garden crops depend more heavily on hand labor but still utilize considerable machinery. Even livestock production utilizes considerable quantities of petroleum, particularly for transporting feed and animals. The amount of petroleum used in livestock production, of course, depends on the availability of feed, which is itself dependent on petroleum. The only historical substitutes for petroleum-fueled machinery are draft animals and manpower. Neither of these possibilities is feasible in the context of national entity survival.

If one assumes, then, that about 75 percent of all farm produce (calorie equivalent) depends directly on the 70 percent of farm petroleum used for farm business, Figure 12 conceptually shows the dependence of output on petroleum availability. It is also assumed that the use of petroleum for private automobiles on farms can be suspended and that only half of the usual household consumption is absolutely necessary. This figure represents about the worst case imaginable; the actual dependence curve should be smooth and above the one shown.

The concentration of the petroleum industry, especially of the refineries, is considered a potential vulnerability of the national entity.[14] Over 50 percent of SIC-29 is in the first six target areas, ordered on petroleum,[12] or in 45 five-kilometer squares.[13] This concentration would make it relatively easy for an enemy to reduce our refining capacity by over one-half by attacking these target areas, and Figure 12 would sugbest that a forty percent loss of agricultural products from this cause only would be possible. In consequence, a significant loss of petroleum would have the following consequences for postattack agriculture:

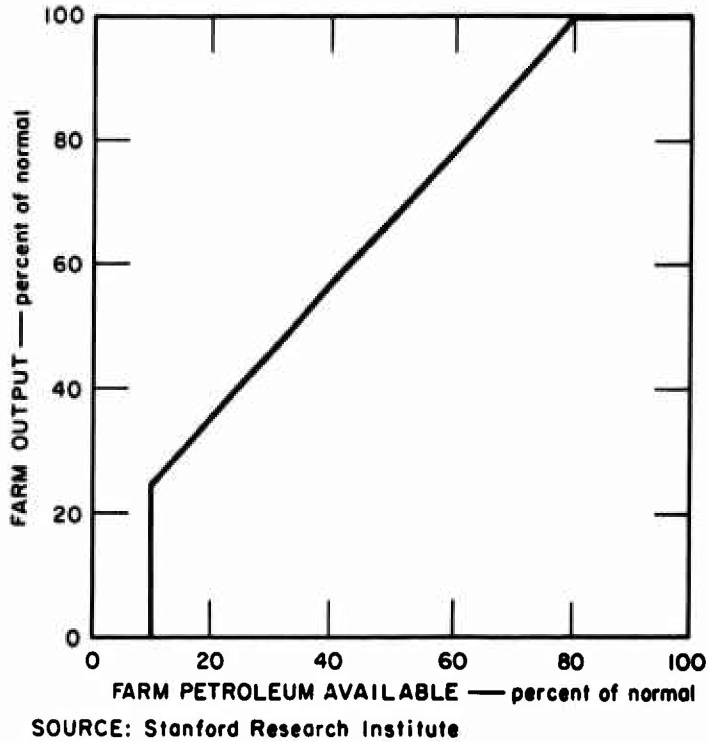


FIG. 12 ASSUMED DEPENDENCE OF FARM OUTPUT ON PETROLEUM

1. A greater share of the surviving petroleum should be diverted to agriculture. This diversion may be difficult in view of the overall shortage of petroleum and the fact that optimistic views of survival potential depend on the assumption of an effectively functioning transportation system that is almost entirely powered by petroleum.

2. A postattack agricultural management system should allocate petroleum to those areas where immediate use of machinery is mandatory and where high yields are expected because of few attack effects. Such allocation decisions will utilize whatever petroleum is available to best advantage by preventing agricultural loss probabilities from becoming additive; i.e., the possibility of having petroleum surpluses in radiation-damaged areas concurrently with petroleum deficits in otherwise untouched areas would be eliminated.

Electricity

The Rural Electrification Administration program resulted in nearly 100 percent electrical service to U.S. farms. However, the only data found for power consumption on farms are quite old.[23] In 1951 power consumption per farm was 5,000 to 7,000 kwh, and this was projected to 30,000 kwh for 1965 by assuming installation of heat pumps and other equipment, mainly for household use. Table 12 shows typical electrical equipment used on farms for farm purposes, with estimated annual electricity used. In general, however, over 50 percent of electricity used on farms is for household use--nearly 90 percent for some types of farms. Farm equipment itself ranged from 3 to 30 percent, lighting from 5 to 26 percent, and water pumping from 2 to 7 percent.[23]

Table 12 also suggests that the type of farm greatly influences the use of electricity. Equipment tends to be specific rather than general.

Table 12

ELECTRICAL EQUIPMENT FOR FARM USE

Equipment	Annual kwh
Dairy and Livestock	
Milking machine (per cow)	27
Milk cooler (per gallon per day)	40
Cream separator	35
Ventilator fan	240
Milkhouse heater	800
Silage unloader	300
Pig brooder (per spring litter)	25
Fence controller	50
Poultry	
Chick brooder (per 100 chicks)	75
Incubator (per 1000 eggs)	180
Mechanical feeder	240
Egg cooler	300
General Farm	
Grain elevator (per 1000 bushels)	3
Roughage elevator (per 100 tons)	10
Hay drier (per ton)	50
Grain drier (per 100 bushels)	100
Feed grinder (per ton)	20
Corn sheller (per 100 bushels)	5
Water Supply	
Pressure system (shallow well)	180
Pressure system (deep well)	240
Pump jack	180

Source: Reference 23.

Dairy and poultry farms, in particular, usually have more electrical equipment and use more power than farms of other types. Farms raising field crops typically use machine shop tools to repair and service their field machines, while livestock operations need equipment to deliver fresh water at suitable temperatures and to process and handle feed, but both use less power than dairies and poultry farms. Water for irrigation frequently is supplied by electric pumps. Because supplying heat for brooding and incubating is dominant for poultry, poultry farms show the most seasonality in electrical demands. Other farms show remarkably uniform demands.[23]

Many of the difficulties caused by short term power losses can be surmounted. Many tasks utilizing electricity can be delayed for the few days outages are expected to last, and others, such as milking, can be done by hand on the smaller farms. Some of the larger dairy and poultry operations have emergency generators. Since irrigation is a relatively minor vulnerability, irrigation pumping is correspondingly minor. The remaining serious problem is pumping water for livestock. (Human needs are presumably supplied by reserves as they are in urban areas.) Range animals depend mainly on surface water supplies, but farmyard animals usually depend on pumped water. A wider distribution of emergency generators and fuel for them would be desirable for livestock operations.

Whether the rural power system is vulnerable to nuclear attack is not a closed question. Blast is the principal threat to both generating and distributing systems. Rural transmission and distribution lines would therefore not be expected to be heavily damaged, but in some cases generating capacity and substations supplying rural areas might be close to targets. Unless restoration times for power supply were unexpectedly long, the principal losses would be experienced in livestock and livestock products and in specialty crops.

Special Aspects of Livestock and Poultry Production

The importance of meat, milk, eggs, and other livestock products in the U.S. diet is unquestioned. Almost one-half of our daily caloric intake comes from livestock and poultry products. About three-fifths of the harvested acreage in the United States goes into animal feed, and perhaps half of the total U.S. acreage is in pasture and range land, usable only for livestock production. These facts suggest that an analysis of postattack recovery potentials depends on accurate assessments of U.S. abilities to produce, process, and distribute meat and related foods.

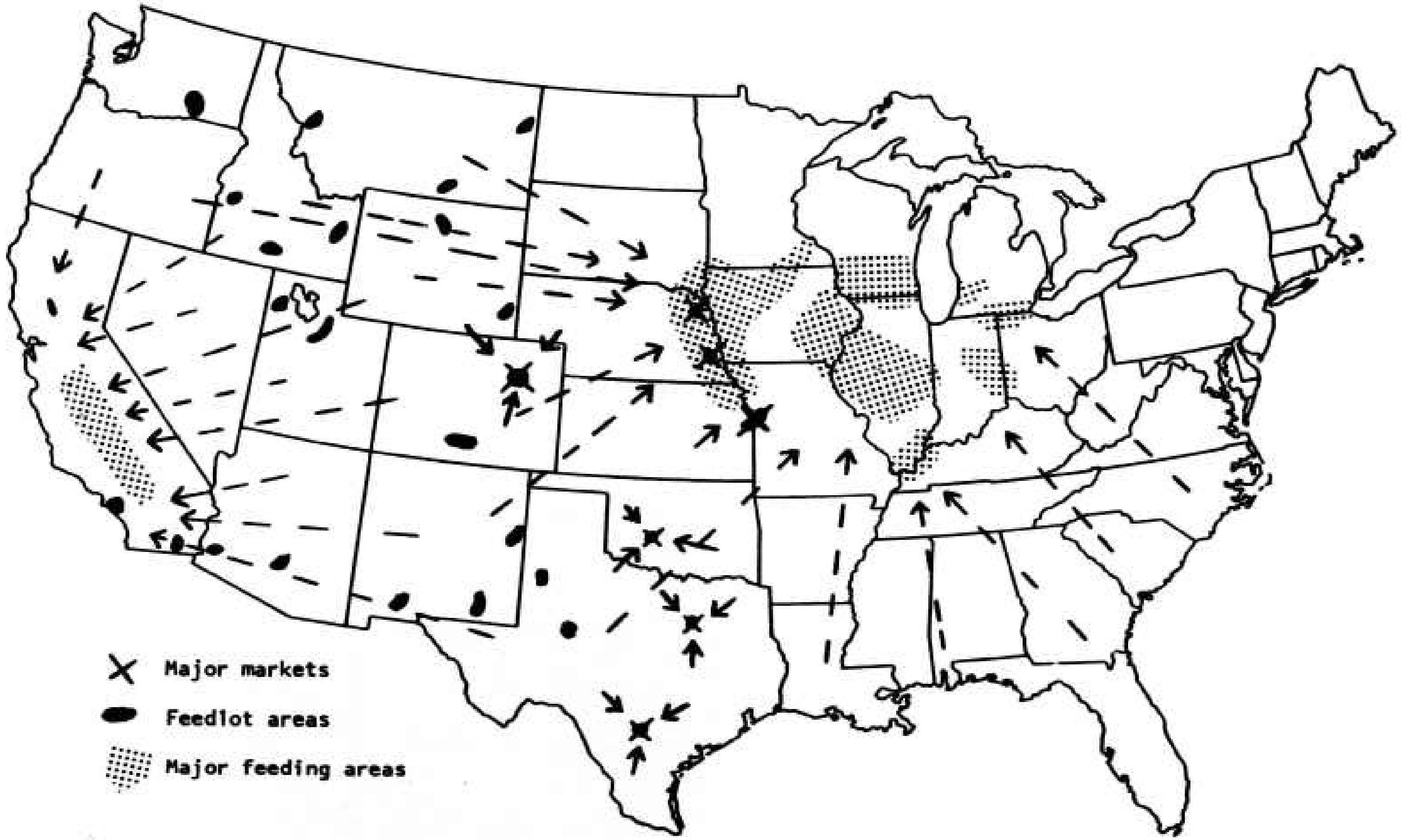
Among the questions raised with respect to the previous assessment of livestock survival[1] was the extent to which new developments in raising livestock and poultry might affect the vulnerability of food production. Specifically, the trends toward finishing beef cattle in large feedlots and toward producing broilers (young chickens sold for meat) and eggs in factory-type operations were considered as potentially concentrating these industries and increasing their vulnerability.

Beef Cattle Production

There are a variety of methods for producing a slaughterable beef or veal animal, but a typical set of steps might be something like the following.[25] A calf is born in a breeding herd on the western range. It is raised on the range with its mother until it is six months to a year of age. It is then sold as a stocker and put on pasture or some other relatively low quality feed for another six months to a year, with the goal of growth rather than improvement of condition. The animal is then sold again as a feeder, and put on a feedlot (with as few as a dozen or as many as 50,000 other cattle) on rich feed for fattening. These feedlots are typically in Nebraska or Iowa (the Corn Belt) or more recently, in California. (See Figure 13.) An average time on feed is about five months, with relatively few cattle being fed less than three or more than six months.[26] Although prior practice would most often have had the animal--at around two years old--sold and moved to central stockyards in Chicago or Omaha, it is probably now more likely that the sale would be directly to a slaughterhouse in the vicinity of the producing (fattening) area. The meat from slaughter would then move under refrigeration to a consuming area some distance away. From conception to ingestion, the beef travels a distance of over a thousand miles.[24]

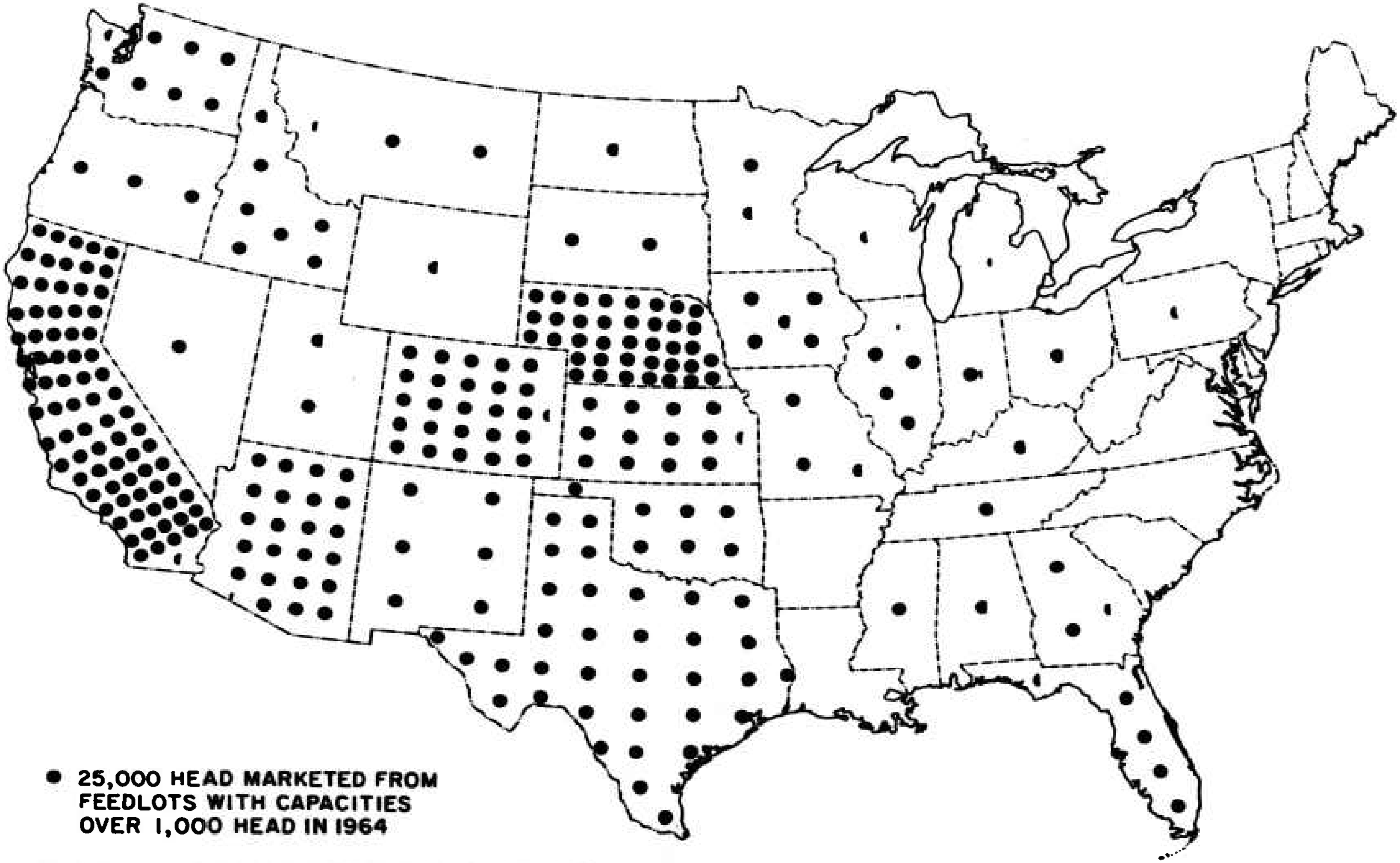
One concern generated by this beef production procedure was that in inventorying cattle, the cattle in feedlots could be missed. The SRI data base, obtained from the 1959 Census of Agriculture,[28] was for "Bulls, Steers, and Calves (on Farms)." Our concern in this instance was not justified, however, because the Census of Agriculture definition of farm is so worded as to include feedlots, and the inventory of cattle by county includes those on feedlots. So long as the finest grid for agricultural resources is by counties, no significant differences will result by considering cattle on feedlots separately from those on pasture or other maintenance. Feedlots are, however, relatively concentrated in a few states as compared to overall cattle concentrations. The marketings of cattle from large feedlots is shown in Figure 14.[29] It would be desirable to determine whether feedlots are typically located near enough to population concentrations that blast and thermal effects might be significant.

Another concern is the question of how well the category of bulls, steers, and (male) calves correlates with total cattle inventories, with beef cattle inventories, with numbers of cattle sold or slaughtered; in fact, how all of these statistics are interrelated. Data from the Census of Agriculture for 1964[30] and from Agricultural Statistics 1966[31] were analyzed to determine such relationships. State by state statistics were



SOURCE: Ref. 26

FIG. 13 MOVEMENT OF STOCKER AND FEEDER CATTLE TO MAJOR MARKETS AND FEEDING AREAS



SOURCE: Stanford Research Institute and Ref. 28

FIG. 14 CATTLE MARKETED FROM LARGE FEEDLOTS compared for this purpose. Some examples of the results are as follows. The ratio of cattle and calves sold per year to the inventory of bulls, steers, and calves ranges from under 1 to over 10, with the larger ratios in states with few cattle of any description. States having large dairy herds naturally also have high ratios. Even for states with over a million bulls, steers, and calves, the ratio varies from 1.6 to 2.6 around the national ratio of 2.1. Ratios of sales to total cattle and calves inventories or beef cattle and calves inventories (total minus milk herd) show similar variations. Ratios of cattle and calves slaughtered commercially to cattle excluding milk cows vary from 0.02 to 31; for states with over 3 million beef cattle, they vary from 0.14 to 1.19, compared with the national ratio of 0.56. Slaughter also correlates poorly with population; Iowa slaughtered nine times as many cattle as New York.

These observations indicate not only that cattle raising practices vary widely over the country, but also that transportation between states specializing in various aspects of the cattle industry is essential for distribution of meat. For example, even though cattle raising is quite dispersed relative to many other resources, and the dispersion appears to be increasing, about two-thirds of the cattle are still west of the Mississippi at any one time, but two-thirds of the population is east of it.[24] That transportation and distribution are becoming increasingly significant in cattle production is also indicated by the relationship between farm values and retail prices of farm products. Farm values have remained relatively constant, while marketing costs have increased rapidly; two-thirds of total civilian expenditures go to marketing now as opposed to one-half twenty years earlier.[32]

The above considerations may be summarized as to significance for agricultural vulnerability. Although trends are toward larger feedlots and more cattle on feed, there is a concurrent trend toward dispersion in the locations of feedlots and slaughter houses (away from the big cities).

These trends should tend to lessen the vulnerability of cattle inventories. On the other hand, transportation has always played a large role in getting meat to the eventual consumer, and trends are toward more use of truck transportation, especially refrigerated. Dispersion tends to increase the number of short hauls compared with long ones, but total ton-mile movements are still large. Transportation and distribution of livestock and livestock products at all stages of production thus appear to be the most critical considerations in the vulnerability of the livestock product system.

Poultry and Eggs

There are many similarities between the trends in the beef cattle and poultry raising industries. Broilers (young chickens sold for meat) and eggs are being produced on fewer numbers of larger farms. Many poultry operations are so concentrated and automated that it is difficult to identify them as agricultural operations, but they are still classified as farms for the purpose of chicken inventories by the U.S. Census of Agriculture.[30]

Although a significant fraction of all poultry products still comes from small flocks widely dispersed on general purpose farms, the trend is toward large special purpose enterprises. Typically, eggs come into a hatchery, where incubation requires about 21 days. The sex of the chicks is determined soon after hatching, and shipping occurs within a day or two. If the chicks are of the egg-laying varieties, all of the males (cockerels) are destroyed. Both males and females (pullets) can be used for meat producing animals (broilers). If the chickens are of the egg varieties, they go to egg ranches and begin laying at about five to six months of age. They lay over 200 eggs a year but are culled out of the flock after about a year or year and a half, usually before two years of age, and sold for meat. Some of the eggs go back to the hatchery to start the process over again, but many of the eggs for this purpose come from chicken breeding specialists. Broiler types go to commercial broiler producers who raise the chickens on rich, balanced feed to marketable size (three to four pounds), sometimes within eight weeks, but usually by the end of three months. These then go to commercial broiler slaughter, cutting, and packing plants and on to the distributing network. Both broiler and egg production can be carried out in highly mechanized and automated facilities, sometimes in combination with one another. All of these enterprises are typically located at some distance from population centers, increasingly in the Southeastern States.[30-36]

The concentration that has occurred both in larger plants and geographically is indicated by the differences in inventories and sales between 1959 and 1964. Table 13 summarizes a few pertinent statistics.[30] Farm numbers generally were halved in five years, but the small number of large farms increased by a similar factor. Although inventories decreased, egg sales increased. Per capita consumption has dropped considerably from 25 years earlier,[37] but seems to be leveling off. Chickens sold from layer flocks were fewer, but broiler sales more than compensated for this small loss and probably represented a moderate increase in per capita consumption of chicken meat.[37] Large farm production of eggs (and culled older chickens) has traditionally been a small part of the total industry but increased by about a factor of three in the five years. Broiler concentration in large operations continues to increase, by a factor of two in the five years. Geographical shifts also continue, with increased production and inventories in the South, mostly at the sacrifice of the North, with the West remaining relatively stable.

These trends seem likely to continue, for economic reasons. Economies of scale[38] and those due to automation imply that large producers will continue to have a competitive advantage. Low labor and building costs in the South favor poultry operations, although cheap feed still favors the North for egg production, while broiler marketing might suggest

Table 13

POULTRY STATISTICS

Category		United States Total	United States Large Farms*	The North Total	The North Large Farms	The South Total	The South Large Farms	The West Total	The West Large Farms
Chickens, 4 months and over									
Farms (thousands)	1959	2,208	2.5	983	0.8	1,082	0.9	143	0.8
	1964	1,211	5.8	542	2.0	594	2.6	75	1.2
Number (millions)	1959	370	46	215	14	105	16	50	16
	1964	343	141	166	40	125	63	52	38
Eggs Sold									
Farms (thousands)	1959	1,115	2.5	726	0.8	331	0.9	58	0.8
	1964	527	5.4	365	1.8	137	2.4	25	1.2
Number (million dozens)									
	1959	3,618	566	2,156	171	826	183	621	211
	1964	4,282	1,952	2,055	552	1,473	841	735	558
Broilers Sold									
Farms (thousands)	1959	42	2.3	8.2	0.4	32	1.6	1.9	0.2
	1964	35	4.4	4.6	0.5	30	3.7	0.9	0.2
Number (millions)	1959	1,419	405	252	72	1,095	300	72	33
	1964	1,915	829	193	88	1,638	677	84	63
Hens and Broilers Sold									
Farms (thousands)	1959	798	2.5	596	0.8	161	0.8	40	0.8
	1964	363	5.3	287	1.7	61	2.4	15	1.2
Number (millions)	1959	220	26	135	8	54	9	31	9
	1964	201	81	100	23	73	38	28	20

* Farms with more than 10,000 chickens over four months of age, or for broilers selling more than 100,000 broilers per year.

Source: Reference 30.

concentration around population centers.[39] Concentration always poses a vulnerability, so that the trends have significance for postattack recovery. On the other hand, poultry accounts for only about 10 percent of livestock and poultry products as far as food value is concerned. Moreover, hypothetical attacks against population or industry generally do not target the South as heavily as other regions, so that the chances of destroying poultry operations with collateral damage are slim; OCD Region 3 had the highest surviving percentage of chickens in attacks SRI A and B, and Region 5 was above average, for example.[1] Stated differently, the trends in the poultry industry make it increasingly vulnerable to an imbalancing attack, but the attacker is unlikely to exploit this vulnerability either intentionally or accidentally.

IV GEOGRAPHICAL IMBALANCES

The damage assessments carried out by the Institute in 1967 showed that agricultural production was sufficient to supply the survivors both with 2500 calories per day for the year after attack and with adequate nutrition in each of the major food groups studied.[1] This was true both for the counterforce attack SRI A and mixed counterforce-countervalue attack SRI B. However, the results were predicated on the assumption that the food could be distributed to the survivors, and the variations in regional survival of crops and livestock suggested that geographical imbalances between food production and consumption could challenge this assumption. This section considers geographical imbalances at the regional level and their possible significance for requirements on the transportation system.

Preattack Patterns

Even though we have characterized agriculture as a highly dispersed resource, this does not mean that it is necessarily highly correlated with population. On the contrary, since population is relatively concentrated, there are significant regional imbalances between production and consumption. Figure 15 gives some idea of the magnitude of these imbalances. We assume that total demand for calories is proportional to population and thus varies from 3.2 percent in Region 8 to 18.2 percent in Region 1.

Production is also based on calories in Figure 15, but the calorie percentages were calculated only for the food groups included in the data base for damage assessment. Food crops included are wheat, rice, soybeans (for oil), potatoes, and sugarbeets (for sugar). Livestock products

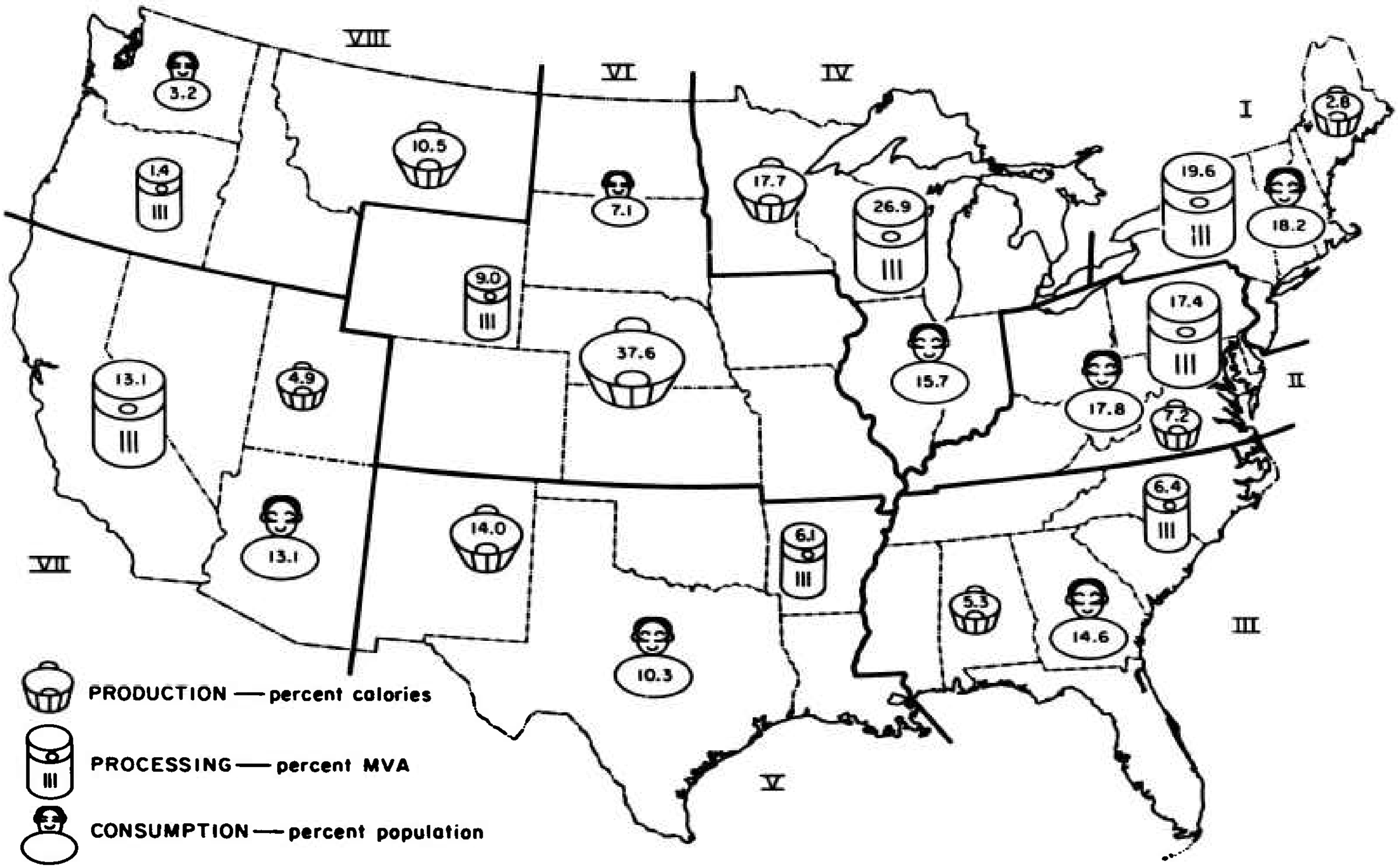


FIG. 15 DISTRIBUTION OF FOOD PRODUCTION, PROCESSING, AND CONSUMPTION

included are chicken meat and eggs, beef, milk, pork, and lamb. The data bases are in terms of acreage harvested for crops and livestock herds for livestock products. These are converted to calories or table weight by empirical conversion factors.* When calories are totaled from these sources, they vary from 2.8 percent in Region 1 to 37.6 percent in Region 6 (the grain belt). The only significant commodities left out are fruits and vegetables, contributing together less than 10 percent of calories in the diet. Inclusion of these products would probably raise the percentages in Regions 3, 5, and 7 slightly. Notice that Region 6 can feed five times the number of people who live there, while Region 1 can feed only 2 out of 13 of its residents.

Food processing is also unevenly distributed, although it tends to correlate better with population than with agriculture. We used manufacturing value added in SIC 20 as a measure of this distribution, since this data base is available for damage assessment. However, MVA in SIC 20 obscures two features of the system. First, aggregation allows no consideration of the variation in distributions among processors of different commodities. Second, it would be reasonable to assume that much more MVA

---

* The large surviving quantities of oils and sugar calculated for Attack SRI A raised a question about the values we had assigned our conversion factors (Reference 1). We reviewed the computation of these factors, again using only gross statistics (Reference 31). Although the factors are still not considered firm, the following corrections appear to be in order:

Soybeans	0.2×10^3 lb/acre and 0.8×10^6 cal/acre
Sugarbeets	4.9×10^3 lb/acre and 8.6×10^6 cal/acre
Eggs	25 lb/chicken and 15×10^3 cal/chicken
Milk	5000 lb/cow and 1.5×10^6 cal/cow

These corrections make the postattack supplies closer to what was expected.

per calorie is recorded for fancy foods than for staples; therefore, the data base is probably biased toward foods not expected to be important in the postattack period. On the MVA basis, nevertheless, the most serious imbalances are in Region 8 (production/processing = 15/2) and in Region 1 (production/processing = 1/7).

The adequacy of our data base for food production can be tested by comparing food requirements for 226 million people (see Reference 1 for the assumed diet) with the extrapolated food production for 1975 of the foods considered in the data base. The results are shown below:

	Produced	Required
Meat and eggs	54.0×10^{9} lb	43.0×10^{9} lb
Fluid milk	102.0×10^{9} lb	89.3×10^{9} lb
Food grains	83.4×10^{9} lb	47.5×10^{9} lb
Potatoes	20.2×10^{9} lb	22.6×10^{9} lb
Oils	4.4×10^{9} lb	5.7×10^{9} lb
Sugar	9.2×10^{9} lb	5.7×10^{9} lb
Food energy	252.8×10^{12}	205.7×10^{12} cal

All categories are oversupplied except potatoes and oils. Sweet potatoes and butter were not inventoried. The excesses indicate exports, in the case of food grains, and more than minimal consumption in the other categories.

The requirements for transportation were inferred by a process that oversimplifies the commodity flows but was necessary for postattack estimates. It was assumed that 100 percent of the food produced flows evenly into the processing system, and that the processed food output in turn flows uniformly and completely into consumers' market baskets. It is then possible to adjust the flows so that regions with an excess of production compared with processing supply areas of deficit production.

The balance can be achieved in an infinite variety of ways and, in practice, is quite complicated. Here, however, we assigned the flows arbitrarily, attempting only to keep the number of flows and distances of flow small. For this purpose we used the approximate inter- and intra-region distances shown in Table 14.

Table 14

INTRA- AND INTER-REGION DISTANCES
(in miles)

	Region							
Region	1	2	3	4	5	6	7	8
1	250	500	950	750	1600	1300	2200	2100
2		250	450	500	1100	950	1850	1900
3			350	650	850	950	1800	1900
4				350	900	550	1450	1400
5					450	650	950	1300
6						500	900	900
7							350	550
8								350

These distances were weighted by the percent of calories moved from producer to processor and from processor to consumer. The inter-regional transfers assumed are shown in Figure 16. Unprocessed food flows 654.1 miles and processed food 391.3 miles in this scheme. Assuming processed food weights are 1.1 times table weight and unprocessed weights are 1.4 times table weight, the total food movement required is

$$(391.3 \times 1.1 + 654.1 \times 1.4) \text{ mi} \times 273 \times 10^{9} \text{ lbs} / 2{,}000 \text{ lbs/ton}$$

$$= 184 \times 10^{9} \text{ ton-miles} \qquad (10)$$

per year. This amounts to 814 ton-miles per capita. Assuming 5.0 gallons of petroleum per 1,000 ton-miles,[40] we obtain a fuel requirement of 21.9 million barrels of petroleum. On a per capita basis, this is 265 barrels per day per 10^6 population. This compares with 213 barrels per

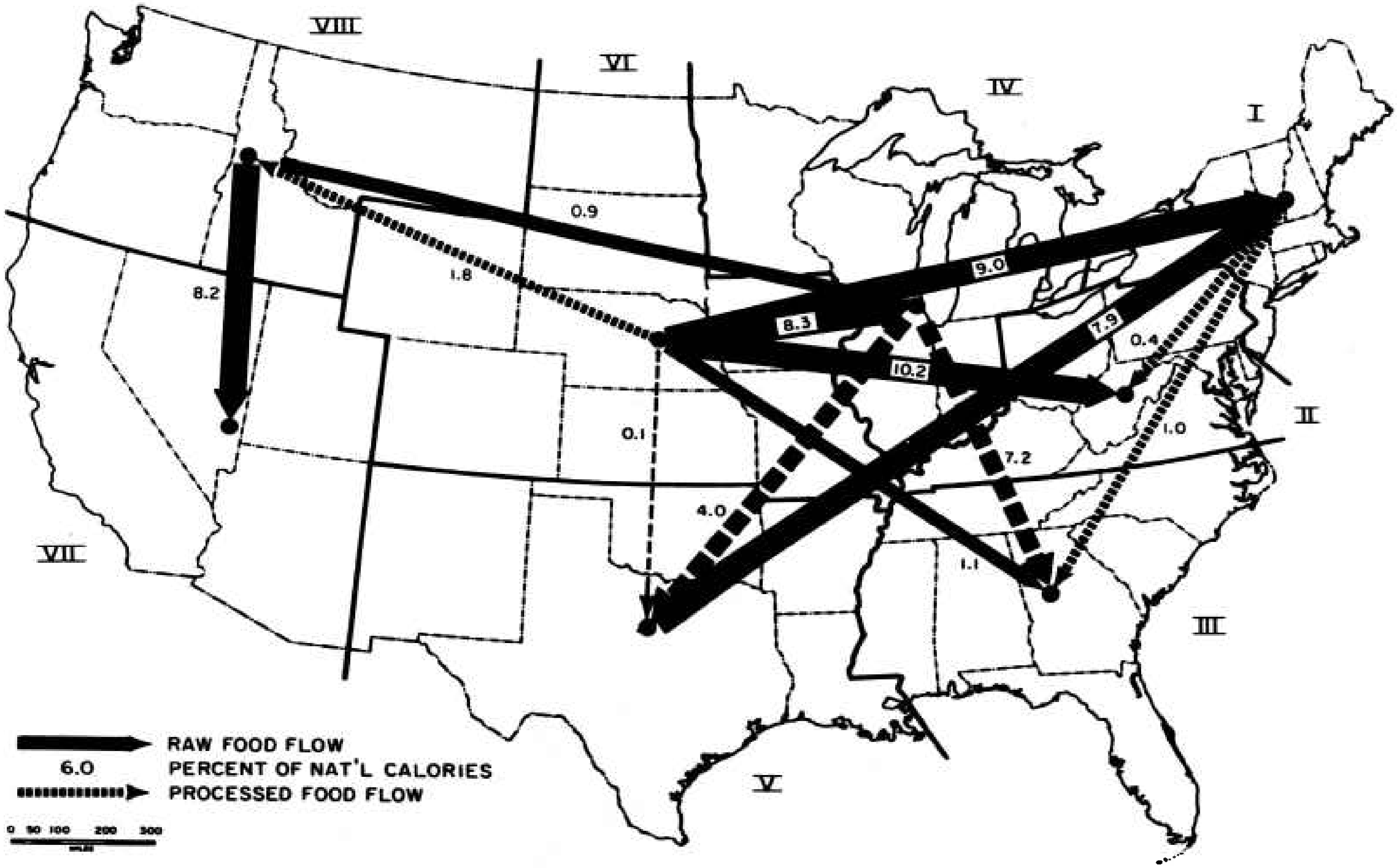


FIG. 16 SIMPLIFIED FOOD TRANSPORTATION FLOW

day calculated for distributing food stockpiles,[14] a figure that is considered only an order-of-magnitude check. Transportation requirements are probably considerably greater because of (1) more complicated commodity flows than assumed and (2) higher requirements for short-haul distribution. Petroleum requirements per ton-mile may be higher than assumed because of the extensive use of truck transport. Commodity distribution especially should be further examined for significance here. Transport of animal feed could also be a factor.

Postattack Patterns

The postattack distributions of population, food processing, food value, commodity groups, and animal feed requirements and supplies are shown in Table 15, with the preattack values for comparison. The same data, expressed as a percentage of the U.S. total, are presented in Table 16. All resources are more heavily damaged in Regions 1, 2, and 7 than for the nation as a whole, while Regions 3, 6, and 8 tend to survive relatively better than any of the others. The overall national damage is summarized below.

	Percent of Preattack Surviving Attack	
	A	B
Population	79.7	60.6
Food processing	68.9	34.6
Food value	71.8	70.7
Livestock requirements	75.7	71.2
Feed crops	83.1	80.9

Because the preattack distributions of resources are so unbalanced relative to one another, however, the changes in the fraction of the national total supplied by each region (by as much as a factor of two) do not make correspondingly large changes in the imbalance. This is particularly true for the agricultural supply because the largest agricultural

Table 15

REGIONAL DISTRIBUTION OF RESOURCES

1975 Projections

	Region								
	1	2	3	4	5	6	7	8	US
Population (millions)									
P*	41.2	40.3	32.9	35.5	23.2	16.1	29.7	7.25	226
A*	32.6	33.9	28.8	31.1	17.6	14.4	15.7	5.43	180
B*	20.9	21.2	27.5	22.3	15.8	12.8	11.4	4.96	137
SIC 20 MVA (billion dollars)									
P	2.37	2.11	0.78	3.26	0.74	1.09	1.59	0.17	12.12
A≁	1.41	1.42	0.67	2.82	0.48	0.76	0.72	0.06	8.35
B≁	0.70	0.73	0.58	1.20	0.26	0.44	0.27	0.03	4.19
Food energy (trillion calories)									
P	7.0	18.1	13.4	44.7	35.4	95.2	12.5	26.5	252.8
A	4.2	10.2	10.9	32.7	28.1	67.0	7.9	20.4	181.6
B	3.2	7.0	10.8	30.8	29.4	68.9	7.2	21.4	178.8
Food grains (billion pounds)									
P	0.4	3.7	1.5	7.7	16.7	39.5	2.1	11.8	83.4
A	0.2	1.3	1.3	4.9	12.4	25.1	1.6	8.4	56.2
B	0.1	0.9	1.3	4.3	14.2	26.6	1.6	8.9	56.8

*P = Preattack.
A = After Attack SRI A.
B = After Attack SRI B.
≁ = Undamaged and Lightly Damaged.

Table 15 (concluded)

	Region								
	1	2	3	4	5	6	7	8	US
Livestock requirements (trillion calories)									
P	12.2	39.7	38.7	90.6	40.3	135.8	21.0	18.5	396.9
A	7.2	25.3	32.3	64.7	32.1	110.9	12.2	15.7	300.3
B	5.0	16.2	31.7	62.0	31.7	108.5	11.4	16.0	282.6
Feed Crops (trillion calories)									
P	4.9	32.9	37.4	119.5	29.0	150.4	5.8	9.0	388.9
A	3.7	25.4	29.5	100.3	21.6	132.2	2.3	7.0	322.9
B	3.2	21.7	29.1	95.7	21.8	132.5	2.9	7.2	314.2

Table 15 (continued)

	Region								
	1	2	3	4	5	6	7	8	US
Meat and eggs (billion pounds)									
P	1.8	5.3	6.2	11.5	5.6	18.4	2.9	2.3	54.0
A	1.1	3.5	5.2	8.4	4.4	15.1	1.6	2.0	41.2
B	0.6	2.2	5.2	8.0	4.4	14.8	1.5	2.0	38.6
Fluid milk (billion pounds)									
P	11.8	16.1	10.2	30.7	7.0	16.9	5.6	3.8	102.0
A	7.0	10.0	8.4	22.2	5.1	13.6	2.3	3.3	71.8
B	5.4	5.6	8.2	21.7	4.9	13.6	1.9	3.3	64.6
Potatoes (billion pounds)									
P	4.5	1.6	1.1	3.3	0.3	2.8	1.8	4.9	20.2
A	3.0	0.9	0.9	3.0	0.3	1.7	1.1	4.5	15.4
B	2.7	0.6	0.8	3.0	0.3	2.0	1.1	4.5	15.0
Oils (billion pounds)									
P	-	0.4	0.5	1.9	0.5	1.1	-	-	4.4
A	-	0.4	0.3	1.7	0.5	1.0	-	-	3.9
B	-	0.3	0.3	1.6	0.4	1.0	-	-	3.8
Sugar (billion pounds)									
P	-	0.2	-	1.6	-	2.9	2.4	2.1	9.2
A	-	0.2	-	1.0	-	2.1	1.6	1.9	6.8
B	-	0.2	-	1.1	-	2.3	1.4	1.9	6.8

Table 16

COMPARATIVE REGIONAL DISTRIBUTIONS
(percent of U.S. total)

	Region							
	1	2	3	4	5	6	7	8
Population								
P*	18.2	17.8	14.6	15.7	10.3	7.1	13.1	3.2
A*	18.1	18.9	16.0	17.3	9.8	8.0	8.8	3.0
B*	15.3	15.5	20.1	16.3	11.5	9.4	8.3	3.6
Food processing								
P	19.6	17.4	6.4	26.9	6.1	9.0	13.1	1.4
A	16.9	17.0	8.0	33.8	5.8	9.1	8.6	0.7
B	16.6	17.3	13.8	28.5	6.2	10.5	6.4	0.7
Food value								
P	2.8	7.2	5.3	17.7	14.0	37.6	4.9	10.5
A	2.3	5.6	6.0	18.0	15.5	36.9	4.4	11.3
B	1.8	3.9	6.1	17.2	16.4	38.6	4.0	12.0
Livestock requirements								
P	3.1	10.0	9.8	22.8	10.2	34.2	5.3	4.6
A	2.4	8.4	10.8	21.5	10.7	36.9	4.1	5.2
B	1.8	5.7	11.2	21.9	11.2	38.4	4.0	5.7
Feed crops								
P	1.3	8.5	9.6	30.7	7.5	38.6	1.5	2.3
A	1.1	7.9	9.1	31.1	6.7	40.9	1.0	2.2
B	1.0	6.9	9.3	30.5	6.9	42.1	1.0	2.3

*P = Preattack.
A = After Attack SRI A.
B = After Attack SRI B.

areas, especially Region 6, are relatively lightly hit. Nationally, therefore, food production can supply food needs, but much of the food may have to be distributed without extensive processing, especially after the SRI B attack. On the other hand, if an attack were to damage the Midwest particularly heavily, the agricultural production might not be able to supply the food processors and consumers in the East.

One measure of the geographical imbalances caused by the attacks is provided by the postattack food transportation requirements. These were inferred in the same way as for the preattack pattern in the previous section, with the following differences. First, in the SRI A attack, the surviving food production could supply 2,760 calories per day per capita, and it was assumed that all food was distributed and consumed. However, on a percent of preattack basis, not all of this food could be processed, and it was assumed that four percent of the food moved directly to consumers, instead of to processors. After Attack SRI B, the food produced was greatly in excess of that required, but processing was seriously damaged, with only one-third of preattack MVA surviving. Therefore, we assumed that only 2,500 calories per day per capita would be consumed, with 30.2 percent of the production going into storage without transportation, and 20.7 bypassing processing and going directly to the consumer. Only 49.1 (= 100 x 34.6/70.7) is processed. The flow of food for the two postattack cases is compared with that assumed for preattack in Table 17. If we assume that the shipping/table weight ratio for producer-consumer is also 1.1, the results for transportation requirements are as in Table 18.

Notice that with this methodology, per capita transportation requirements are actually smaller after attack than before for these attacks. In both cases, the heavy preattack concentrations of processing and population in the Northeast and Pacific Southwest are reduced relative to the food producing regions, so that reduced hauls need be made. In the case

Table 17

FOOD FLOWS - CALORIE BASIS

From Region Producer -	To Region Processor	Percent of Food Produced Preattack	SRI A	SRI B	Miles Shipped (weighted) Preattack	SRI A	SRI B
1	1	2.8	2.3	1.8	7.0	5.8	4.5
2	2	7.2	5.6	3.9	18.0	14.0	9.8
3	3	5.3	6.0	6.1	18.5	21.0	21.4
4	4	17.7	18.0	14.0	62.0	63.0	49.0
5	5	6.1	5.6	3.0	27.4	25.2	13.5
6	6	9.0	8.7	5.2	45.0	43.5	26.0
7	7	4.9	4.4	3.1	17.2	15.4	10.8
8	8	1.4	0.7	0.3	4.9	2.5	1.1
4	1	-	-	0.7	-	-	5.2
5	1	7.9	-	-	126.4	-	-
5	3	-	1.7	0.7	-	14.5	6.0
5	4	-	6.5	-	-	58.5	-
6	1	9.0	13.9	5.7	117.0	180.7	74.1
6	2	10.2	10.7	4.6	96.9	101.6	43.7
6	3	1.1	-	-	10.4	-	-
6	4	8.3	3.6	-	45.7	19.8	-
8	4	0.9	4.4	-	12.6	61.6	-
8	7	8.2	3.9	-	45.1	21.5	-
	Total				654.1	648.6	265.1

Table 17 (continued)

From	To	Percent of Food Produced			Miles Shipped (weighted)		
Region	Region	Preattack	SRI A	SRI B	Preattack	SRI A	SRI B
Producer -	Consumer						
5	5	-	1.7	2.4	-	7.7	10.8
6	6	-	-	1.4	-	-	7.0
7	7	-	-	0.9	-	-	3.2
8	8	-	2.3	2.2	-	8.0	7.7
4	1	-	-	2.5	-	-	18.8
5	3	-	-	7.2	-	-	61.2
6	2	-	-	2.3	-	-	21.7
8	7	-	-	1.8	-	-	9.9
	Total					15.7	140.3
Processor -	Consumer						
1	1	18.2	16.2	8.2	45.5	40.5	20.5
2	2	17.4	16.3	8.5	43.5	40.8	21.2
3	3	6.4	7.7	6.8	22.4	26.9	23.8
4	4	15.7	17.3	11.4	55.0	60.6	39.9
5	5	6.1	5.6	3.0	27.5	25.2	13.5
6	6	7.1	8.0	5.2	35.5	40.0	26.0
7	7	13.1	8.3	3.1	45.8	29.0	10.8
8	8	1.4	0.7	0.3	4.9	2.5	1.1
1	2	0.4	-	-	2.0	-	-
1	3	1.0	-	-	9.5	-	-
4	1	-	1.9	-	-	14.0	-
4	2	-	2.6	-	-	13.0	-
4	3	7.2	8.3	-	46.8	54.0	-
4	5	4.0	2.3	2.6	36.0	20.7	23.4

Table 17 (concluded)

From Region	To Region	Percent of Food Produced: Preattack	SRI A	SRI B	Miles Shipped (weighted): Preattack	SRI A	SRI B
Processor - Consumer (continued)							
6	5	0.1	0.2	-	0.7	1.3	-
6	7	-	0.5	-	-	4.5	-
6	8	1.8	-	-	16.2	-	-
	Total				391.3	373.0	180.2
Producer - Storage							
5	5	-	-	3.1	-	-	-
6	6	-	-	19.4	-	-	-
8	8	-	-	7.7	-	-	-

Table 18

TRANSPORTATION REQUIREMENTS FOR FOOD

	Preattack	SRI A	SRI B
Producer-processor (miles)*	915.7	908.0	371.1
Producer-consumer (miles)⌿	-	17.3	154.3
Processor-consumer (miles)⌿	430.4	410.3	198.2
Total travel (miles)	1,346.1	1,335.6	723.6
Total weight (10^9 lbs)≠	273.2	195.4	186.5
Total haul (10^9 ton-miles)≠	183.9	130.5	67.5
Per capita haul (ton-miles)≠	814	725	493

* Weighted by 1.4
⌿ Weighted by 1.1
≠ per year

of SRI B, we additionally assumed that significant quantities of food either went into surplus with no transportation requirement, or bypassed processing with consequent reduced transportation requirement. However, in both cases the individual hauls would tend to be shorter after attack, a great deal of switching from rail to truck might be necessary, and total petroleum requirements might be greater.

Significance

The food transportation requirement per capita is not expected to be significantly greater after the attacks specified, then, assuming that the aggregate flows of food value between regions are sufficient to characterize the problem. Because this assumption is so dominant, however, imbalancing attacks directed at the food production, processing, and distribution systems cannot yet be shown to be infeasible. We have not even considered the very real possibility that food marketing and distribution centers, located often in prime target areas, could not function effectively in a damaged environment. We remain concerned that commodity imbalances may occur, putting a heavier strain on the transportation system than calculated here. The problem of efficient management of the distribution of food is clearly important in this context because the ordinary marketing mechanism will be disrupted and, even intact, is based on preattack distributions of producers and consumers.

V SUMMARY AND CONCLUSIONS

Selected aspects of the vulnerability of U.S. agriculture to nuclear attack were investigated. The study areas can be roughly divided into sensitivity studies, agricultural practices, and geographical imbalances.

Sensitivity studies were conducted relative to the date of attack, foliar contamination parameters, and vulnerability criteria. A good choice for the most vulnerable month of attack is June. If U.S. agriculture as a whole is considered, the vulnerability does not vary too rapidly with date of attack, although during the late fall and early winter it may experience only half the damage it would in June. Results for individual crops or regions are much more sensitive. The sensitivity to foliar contamination parameters was investigated using an improved beta dose model. A variety of foliar contamination models were tested with ranges of the retention factor, f_{ℓ}, and the soil roughness attenuation factor, Q_{β}. None of the uncertainties in the parameters or models lead to differences in the total dose by factors of more than about two, except in extreme cases. An increase in the total dose by a factor of two would have essentially the same effect as reducing the dose criteria for damage by half. Such a reduction leads to a variation of crop survival of less than ten percent. Since so many other factors can influence the results by this amount or more, a large effort for the purpose of improving models and determining parameters more precisely does not seem justified. However, the status of fallout vulnerability of crops and livestock should be reviewed periodically, perhaps every five years, to determine whether changes in the knowledge of fallout effects or in potential attack patterns might be significant enough to warrant development of new models and data.

The agricultural practices surveyed were the application of fertilizers and pesticides, irrigation and cultivation, farm use of petroleum and electricity, and trends in cattle and poultry production. Availability of petroleum and fertilizers would appear to be the most serious questions for the vulnerability of agriculture. The main food and feed crops are produced almost exclusively with the aid of petroleum powered mechanical equipment. They are also quite responsive to changes in soil nutrients and are currently receiving near optimal fertilization. Loss of fertilizers could conceivably cut production in half. Pesticides are probably less important than the above but more important than irrigation, cultivation, and electricity for the production of the main food and feed crops. Fruits, vegetables, potatoes, sugarbeets, and rice are much more dependent on the last mentioned agricultural practices, and dairy, poultry, and other livestock products depend on electricity; thus the nutritional balance and palatability of the postattack diet might be affected. Cattle production trends are toward continued dispersion, with the concomitant low vulnerability. However, transportation appears to be increasingly essential to production and may constitute a vulnerability. Poultry trends are toward increasing concentration, but in areas of relatively low target value. Livestock practices, therefore, are not at the present particularly sensitive as potential postattack problems. Most of these conclusions support those of an eight-year-old study of similar questions with the possible exception that electricity was judged a greater potential vulnerability at that time. Another review is suggested after about the same time lapse. In the meantime, the dependence of farm production on petroleum and fertilizer should be reinvestigated in more detail, and damage assessment models should be developed.

Geographical imbalances between food production, processing, and consumption were investigated on a regional basis. Results were obtained both for preattack patterns and after standard attacks (1975 time frame).

The preattack imbalances are so striking that further imbalances caused by an attack are not likely to be very noticeable, per se. For the postulated attacks, in fact, the imbalance appeared to lessen with respect to the requirements made on food transportation. However, the results were based on gross measures of the resources--food value in calories for production, manufacturing value added for processing, and population for consumption. Investigation of commodity imbalances might paint a more disturbing picture. Management of distribution was also suggested as a potential vulnerability.

Management, as usual in postattack studies, again seems to be the key to the whole agricultural situation during the postattack period. Even though the combined effects of fallout radiation, petroleum shortages, and fertilizer deficiencies could stress the agricultural system, production is still likely to exceed minimum survivor demands. Because of extensive disruption of processing and distribution channels, as well as of the normal patterns of demand and supply, preattack market systems may not be sufficient to get food from producers to consumers in time. A postattack information and management system with the function of determining where resources are available and where they are needed would be desirable. The Department of Agriculture, with its network of county agents, is the logical administrator for such a system. The framework for gathering and disseminating information is already established, and a civil defense function is also operating. It is suggested that these two functions be more closely tied to a management information system that is structured to enable allocation decisions to be made quickly and effectively on the basis of available information.

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